Beam Induced Backgrounds: CDF Experience

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Outline

Tevatron and CDF

Instrumentation/Measurements

- Losses
- DC Beam

Effects Observed at CDF (sources/cures)

- Single event effects (SEE)
- Chronic radiation damage
- Physics Backgrounds

Accelerator Improvements

- Measurements
- Instrumentation

Summary

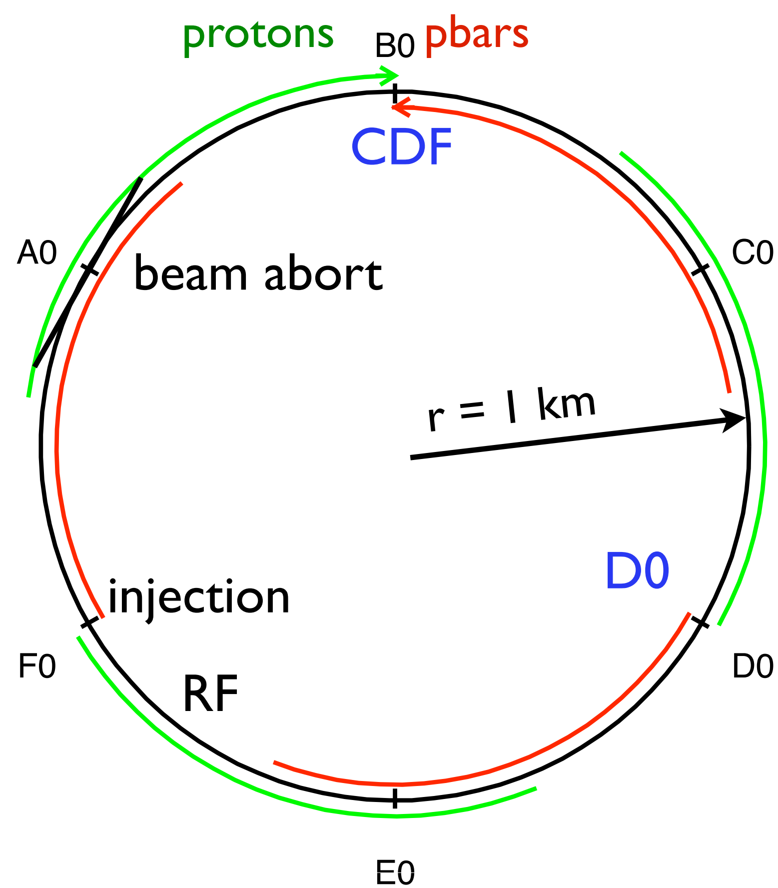
Work by many machine and experiment people

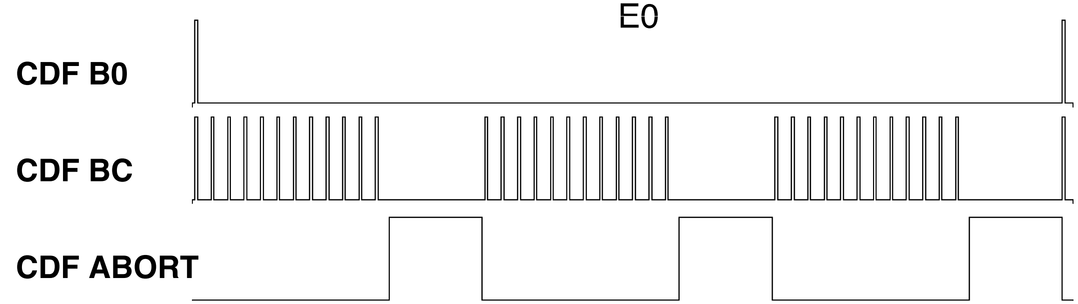
Tevatron Beam Structure

Beam Parameters

interaction regions	2	B0(CDF) D0(Dzero)
beam energy	980 GeV	
# bunches	36	(3 trains of 12 bunches)
bunch length	1 ns	
bunch spacing	396 ns	
abort gap	2.6 μs	
protons/bunch	30×10^{10}	
pbars/bunch	8×10^{10}	
luminosity	2.8×10^{32}	$cm^{-2}s^{-1}$
RF frequency	53 MHz	

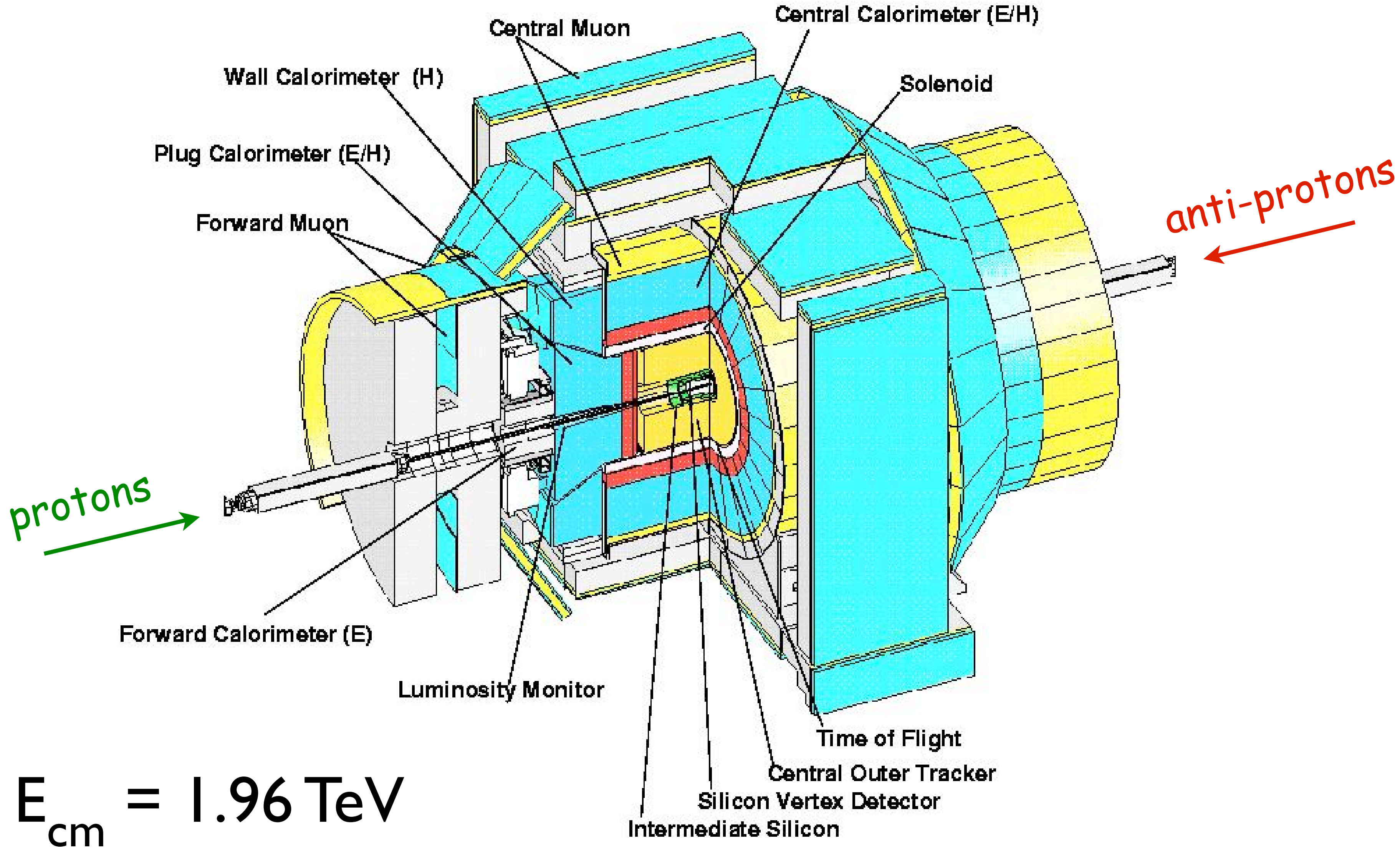
Tevatron





Both beams in same vacuum pipe

CDF-II Detector(G-rated)



$E_{cm} = 1.96$ TeV

Measuring Beam Losses/Halo at CDF

Losses/Halo rates measure beam conditions/risk

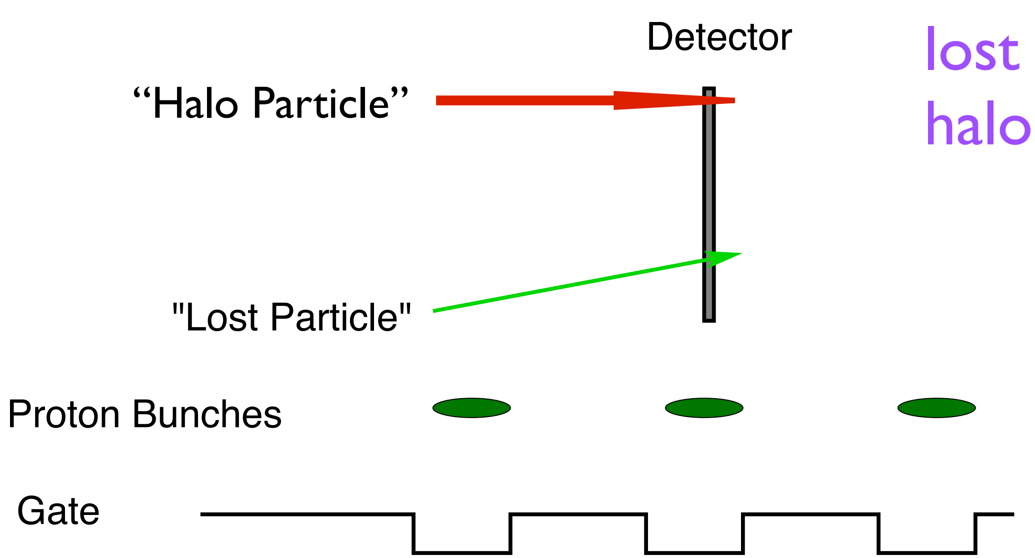
Beam Losses all calculated in the same fashion

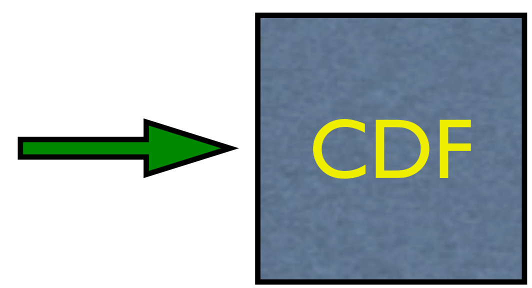
- Detector signal in coincidence with beam passing the detector plane.
- ACNET variables differ by detector/gating method.
- Gate on bunches and abort gaps

Definitions:

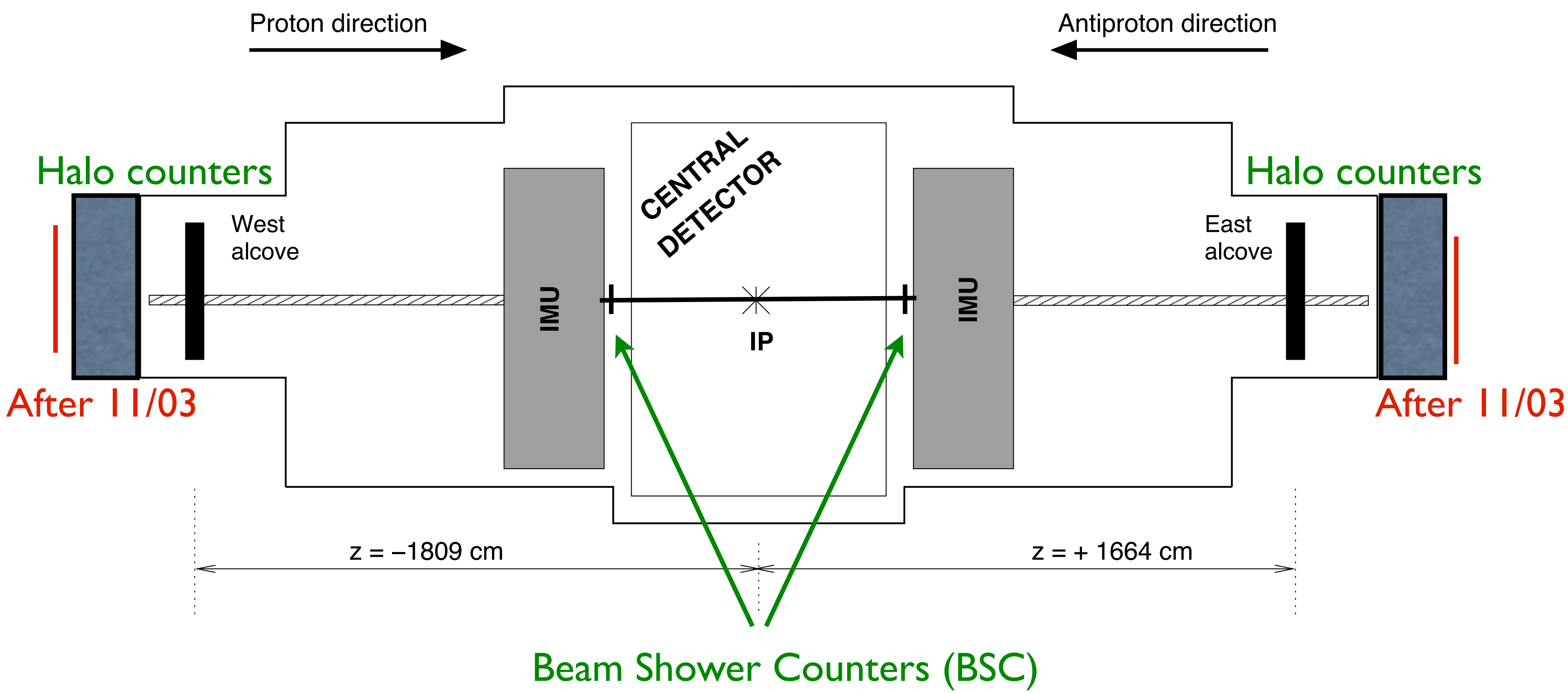
lost particles: close to beam

halo particles: far from beam





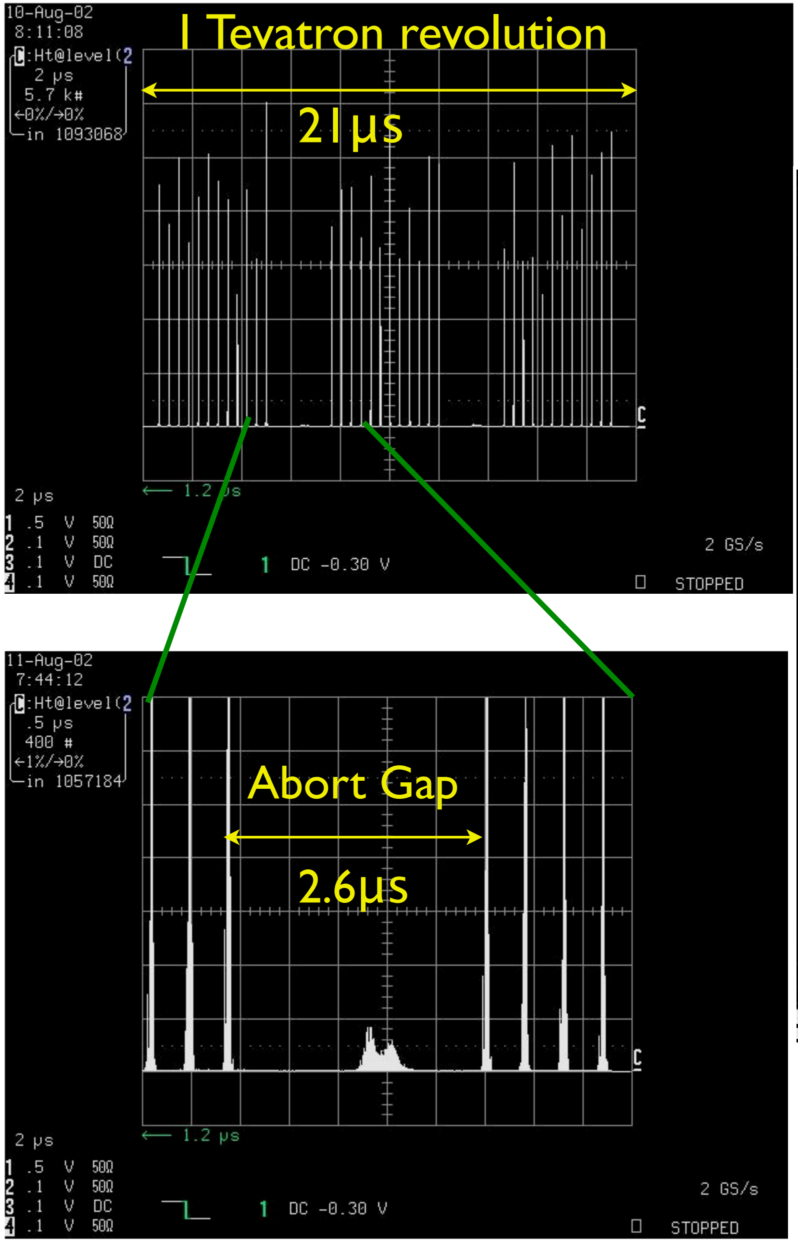
Beam Monitors



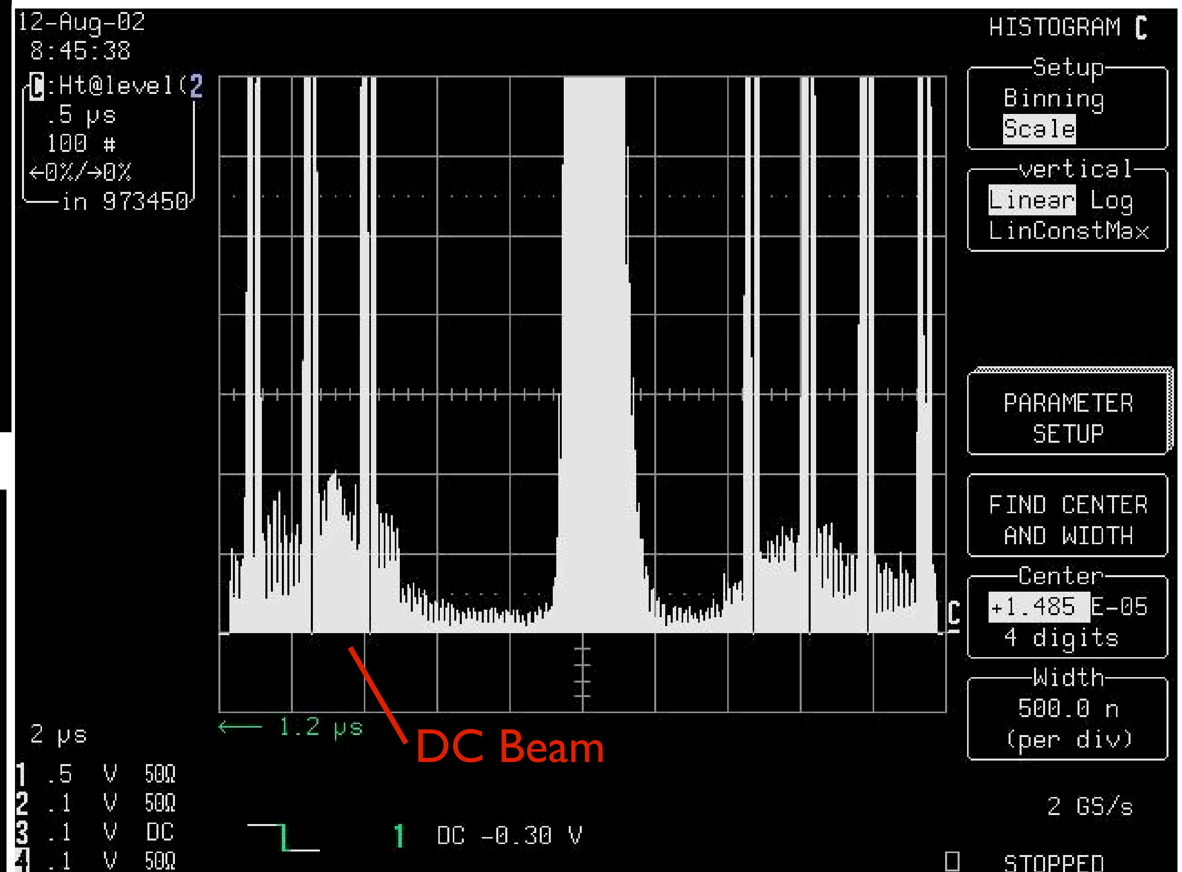
BSC counters: monitor beam losses

Halo counters: monitor beam halo and abort gap

Beam Structure (from losses)



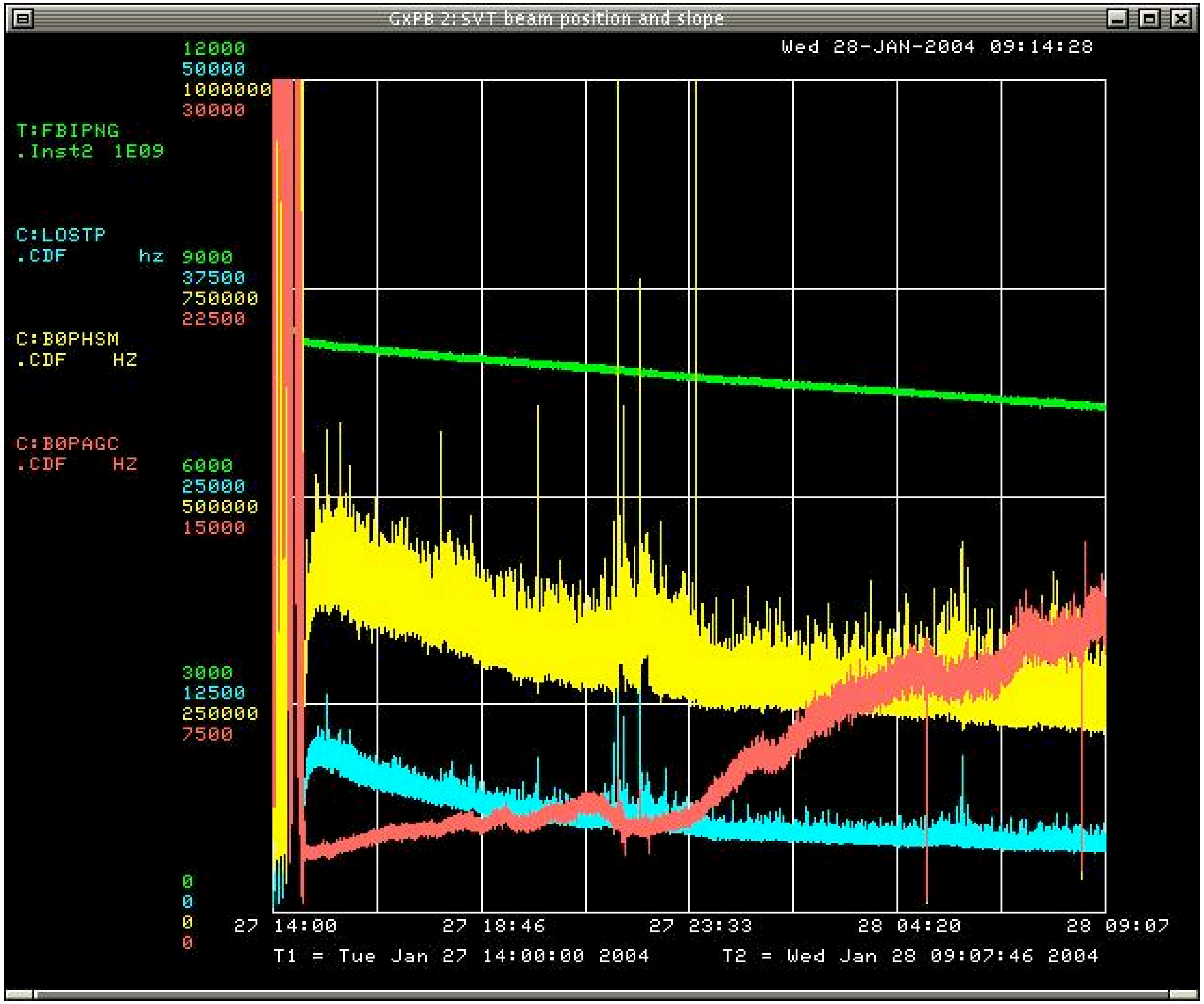
Not all beam is in bunches!
beam in abort gaps => dirty aborts



Note: detector reset cycles during abort gaps susceptible to abort gap losses.

Monitor Experience

“Typical Good Store”



proton beam current

proton abort gap halo

proton halo

proton losses

Abort Gap Monitors

"DC" Beam in Abort Gap

- Risk to detectors on abort (acute radiation damage)

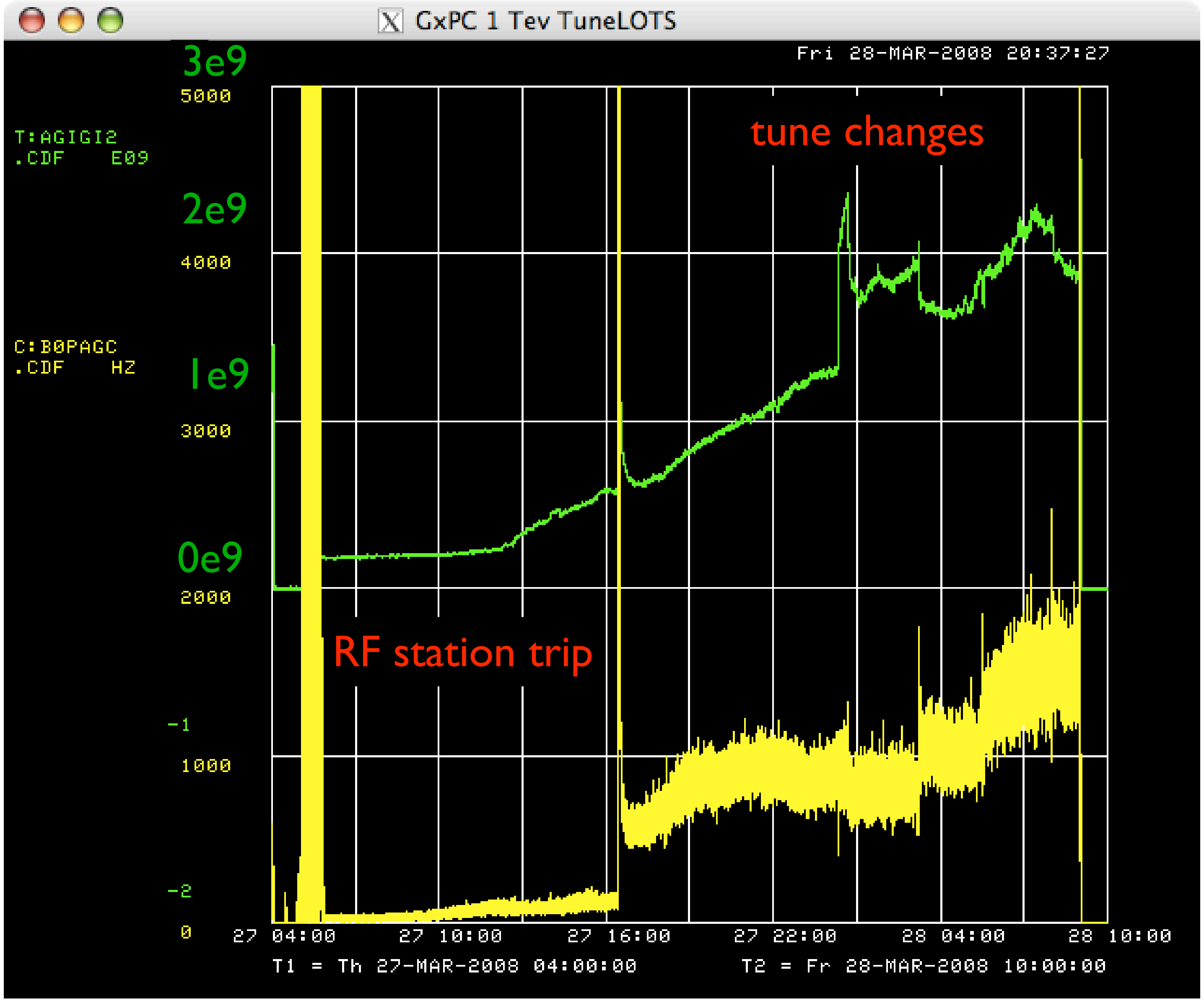
Abort Gap Halo (losses)

- fast
- VERY sensitive
- sensitive to ANY problem in Tevatron
  - good canary for experiment
  - bad debugging tool for accelerator

Sync. Light Measurements

- "direct" measure of beam in abort gap
- slow

Abort Gap Beam & Losses



abort gap beam (sync. light)

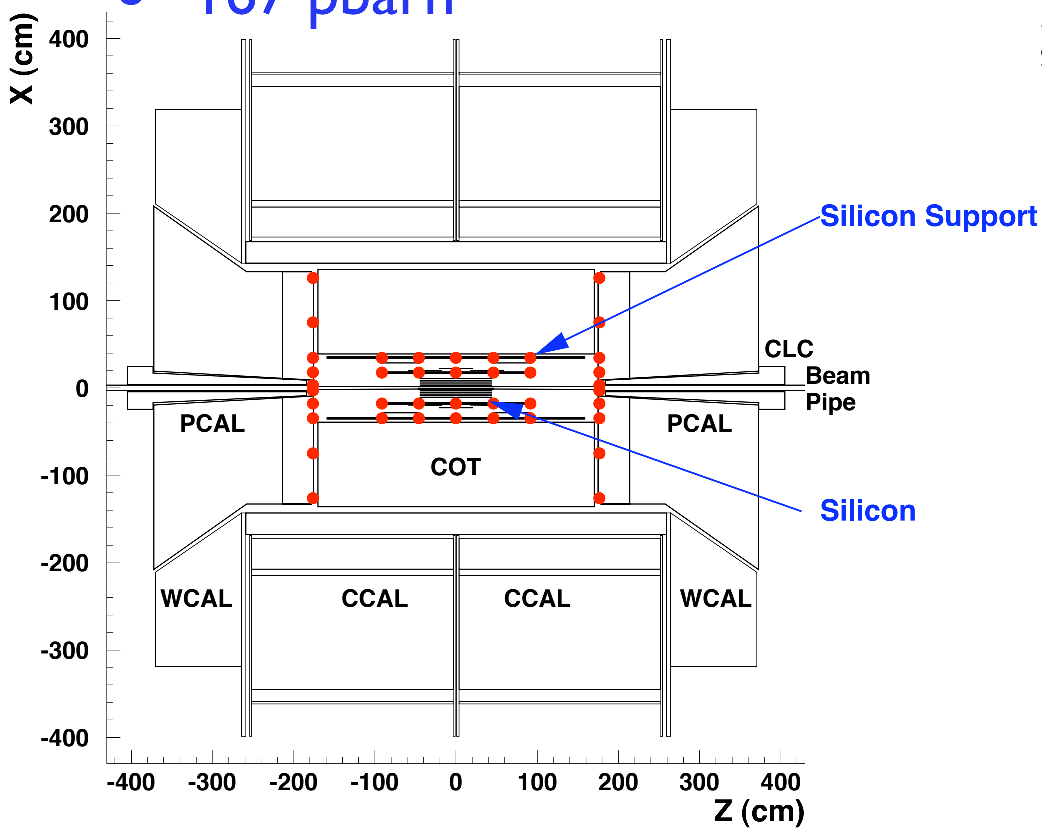
abort gap losses (counters)

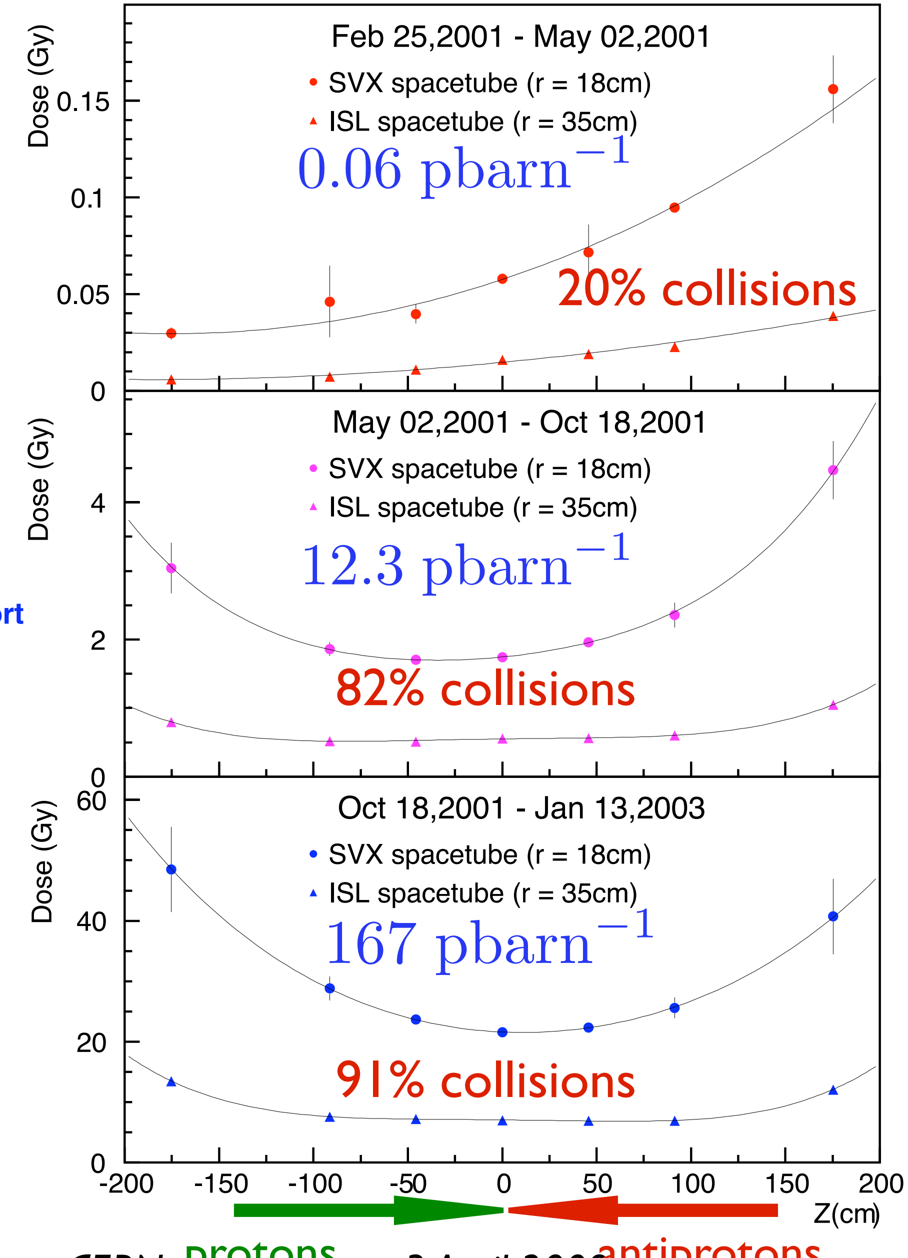
Beam Radiation Measurements

TLDs installed in tracking volume

3 exposure periods

- 0.06 pbarn^{-1} (p-loss dominated)
- 12.3 pbarn^{-1}
- 167 pbarn^{-1}



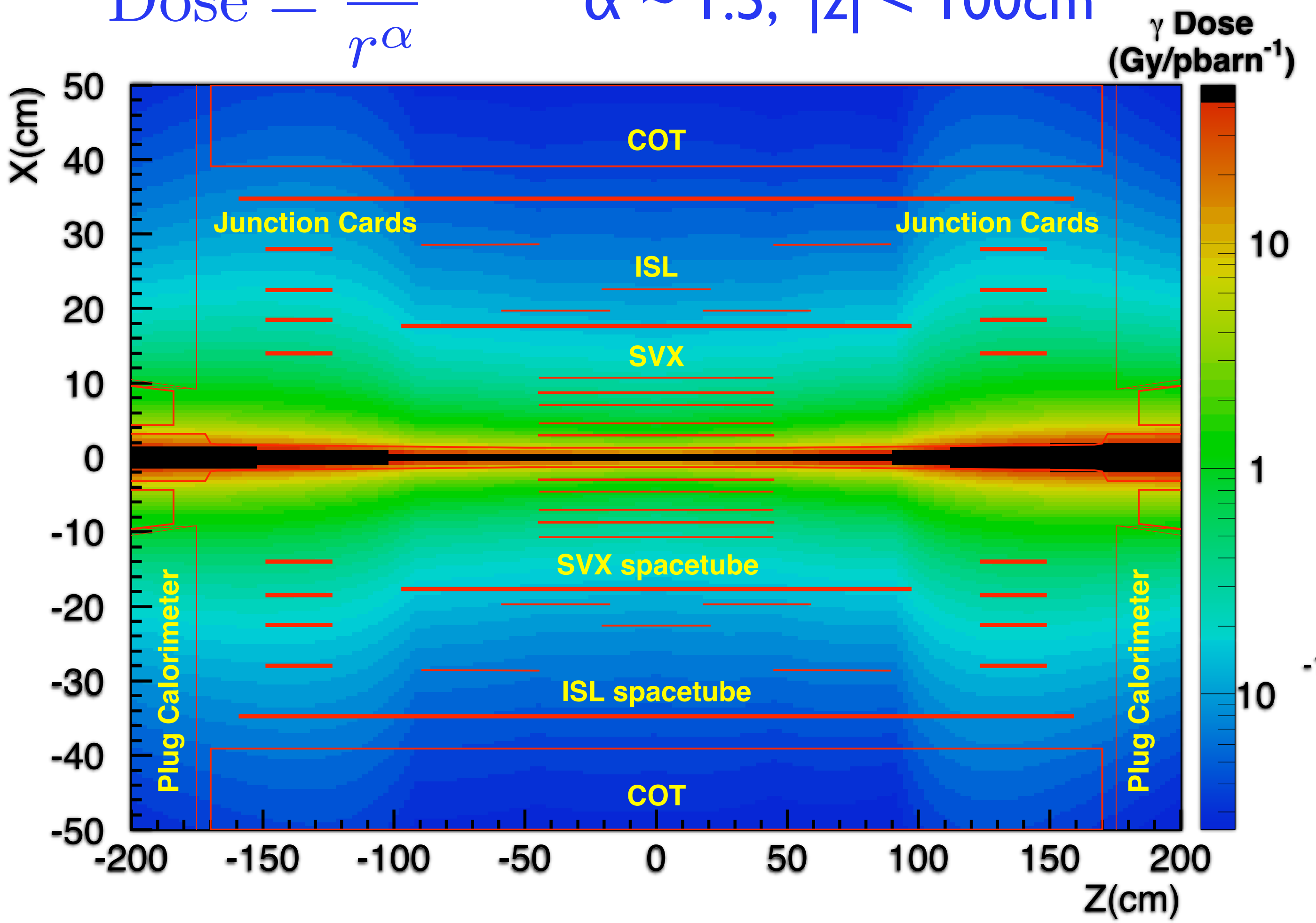


Radiation from Collisions

TLD measurements + model

r measured transverse to the beam

$$\text{Dose} = \frac{A}{r^{\alpha}}$$ α ~ 1.5; |z| < 100cm



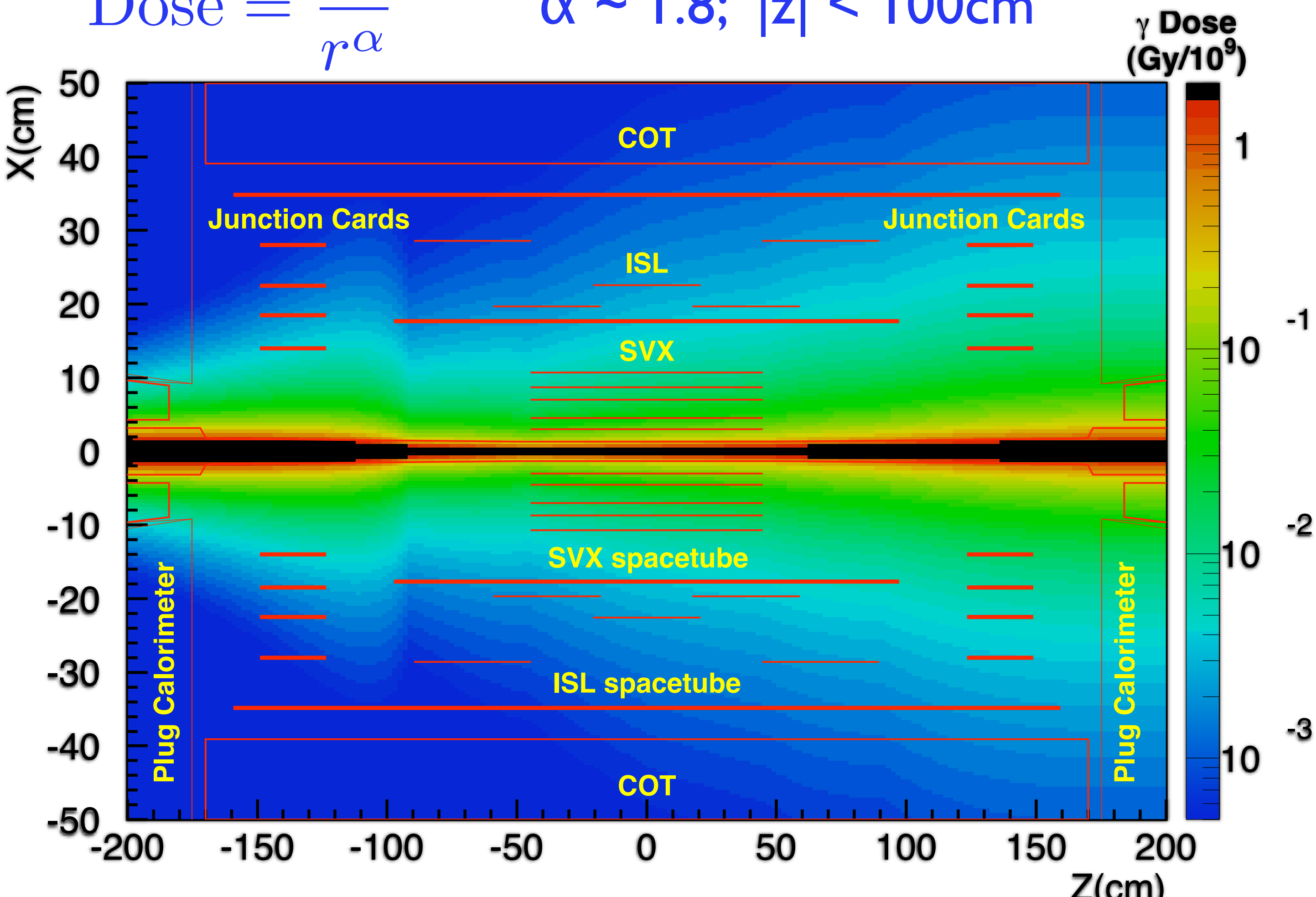
Radiation from Beam Losses

TLD measurements + model

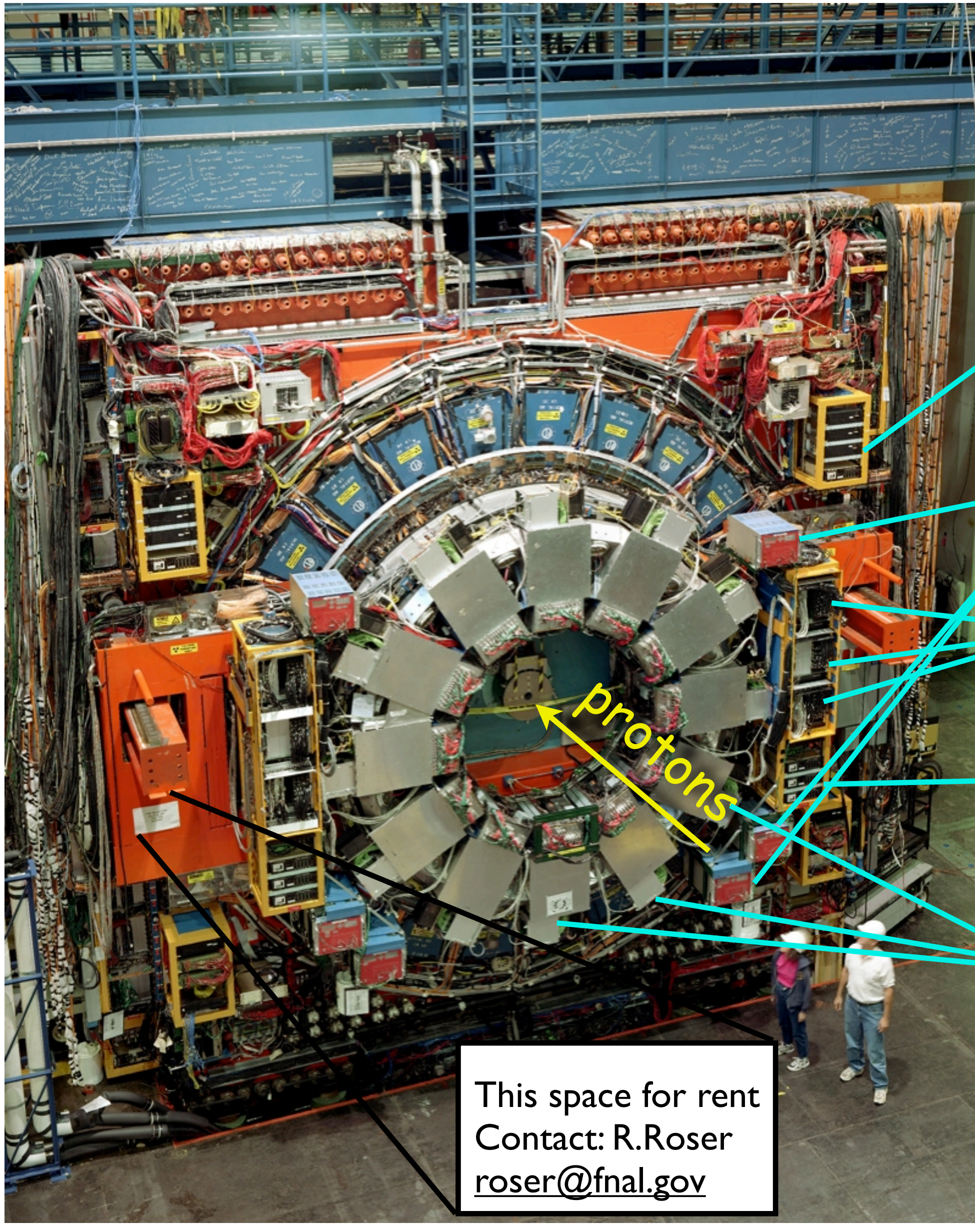
r measured transverse to the beam

$$\text{Dose} = \frac{A}{r^{\alpha}}$$

$\alpha \sim 1.8$; $|z| < 100$cm



CDF Detector (Adults Only)



Readout, control and support electronics located on the detector:

- 5kW custom low voltage (LV) switching power supplies
- Commercial remotely operated high voltage (HV) switching power supplies
- Custom digitizing and readout electronics 9U VME crate (FPGA based)
- 1 kW commercial low voltage (LV) linear power supplies.
- Custom digitizing and readout electronics 6U VME crate (FPGA based)

Operational Problems

Custom low voltage switching power supplies

- catastrophic component failure only with beam present
- average ~3 failures/week
- 12 failures in single day (St. Catherine's day massacre)
- single event burnout (SEB) of power MOSFET

Commercial high voltage switching power supplies (CPU controlled)

- "soft" failure when beam present
- loss of communication/cpu hang
- loss of calibration constants
- 10% of non-accelerator down time due to problem+recovery

Custom detector readout electronics (Shower Maximum, SMX, system)

- soft failure when beam present
- only systems near beam line fail
- communication interrupt/hang
- 6% of non-accelerator down time due to problem+recovery

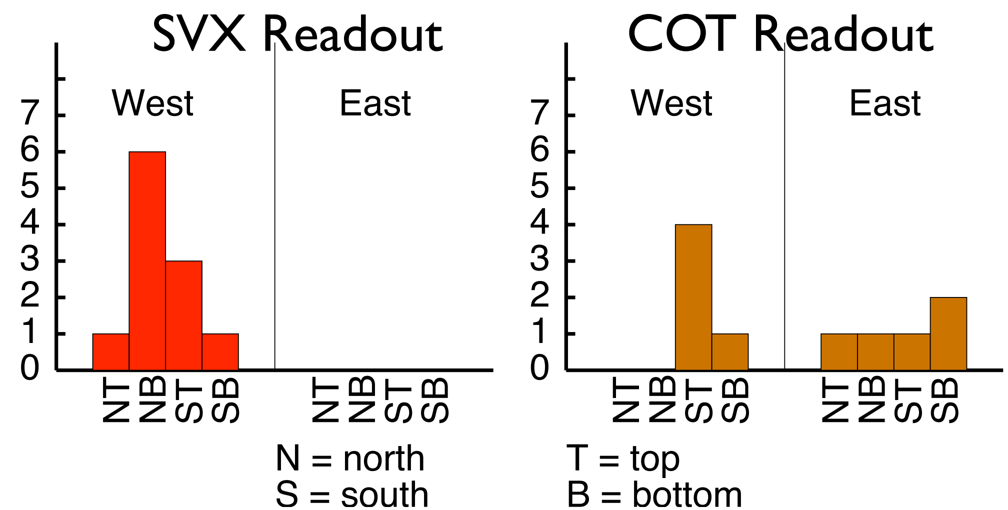
Low Voltage Power Supply Failures

Failure Characteristics

- Position Dependent
- Beam Related

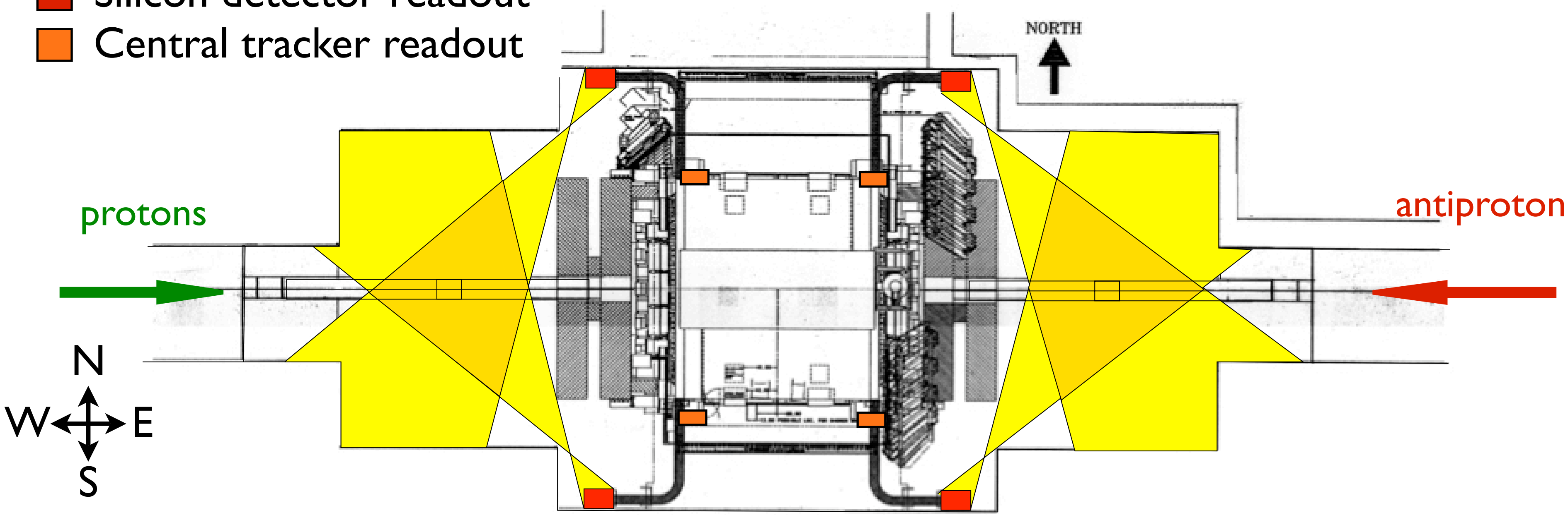
Experiments show focusing quads are a line source of radiation

Failure Locations



Silicon detector readout

Central tracker readout



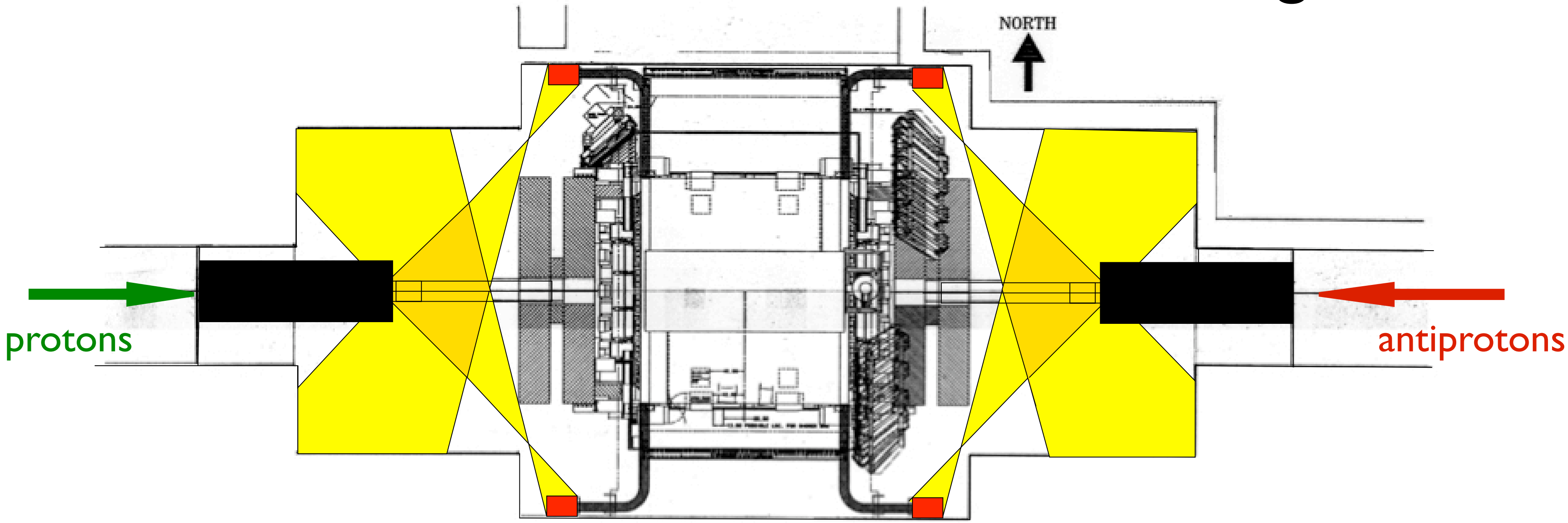
Radiation and Shielding?

Scintillation counter measurements show low beta quadrupoles form a line source of charged particles.

Power supply failure analysis shows largest problem on the west (proton) side of the collision hall.

Shielding reduces ionizing radiation by 25%

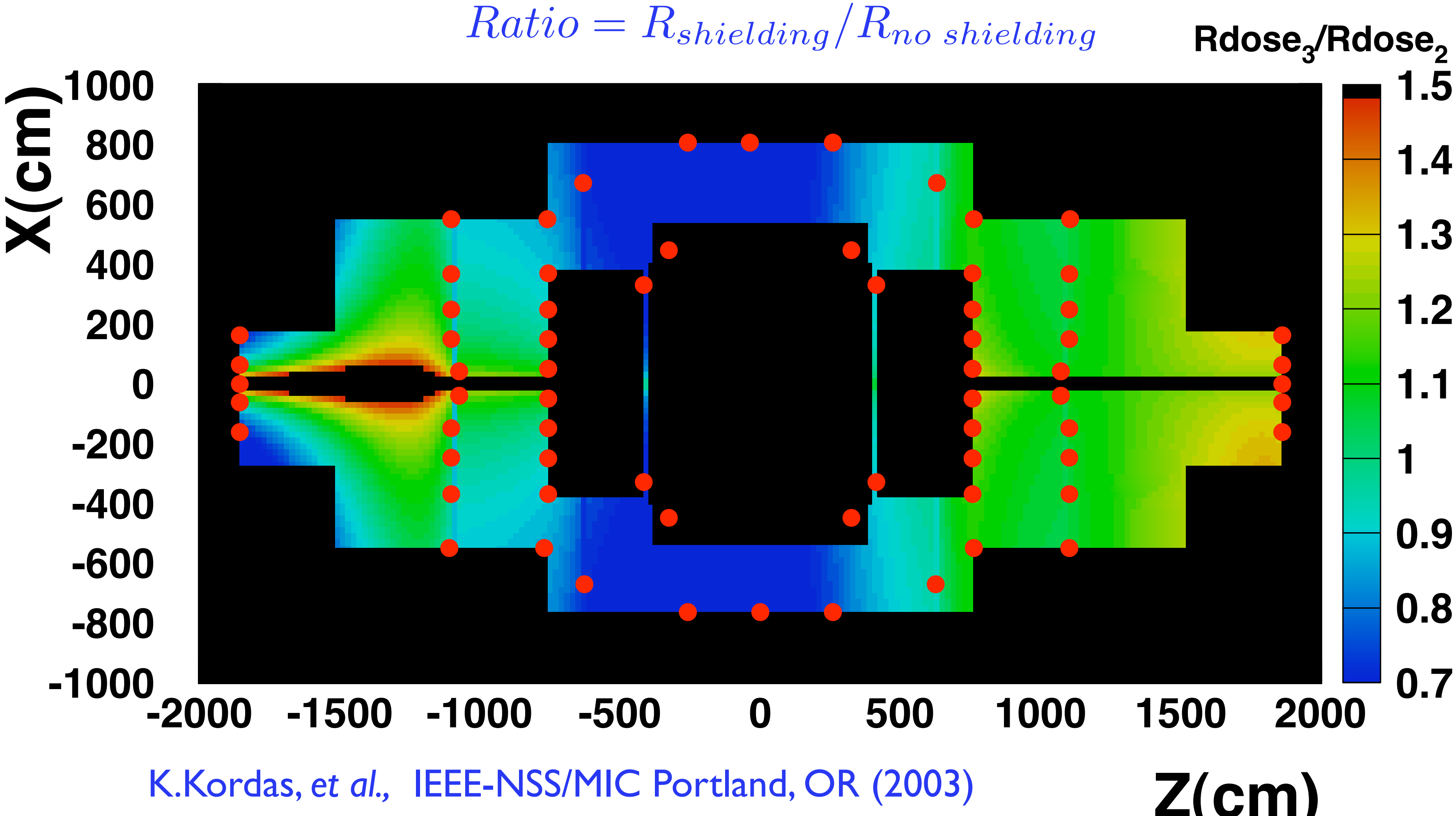
CDF Detector w/ additional shielding



Collision Hall Ionizing Radiation

Thermal luminescent dosimeter (TLD) measurements
Shielding installed on proton side only.
25% reduction in radiation confirmed with measurements.

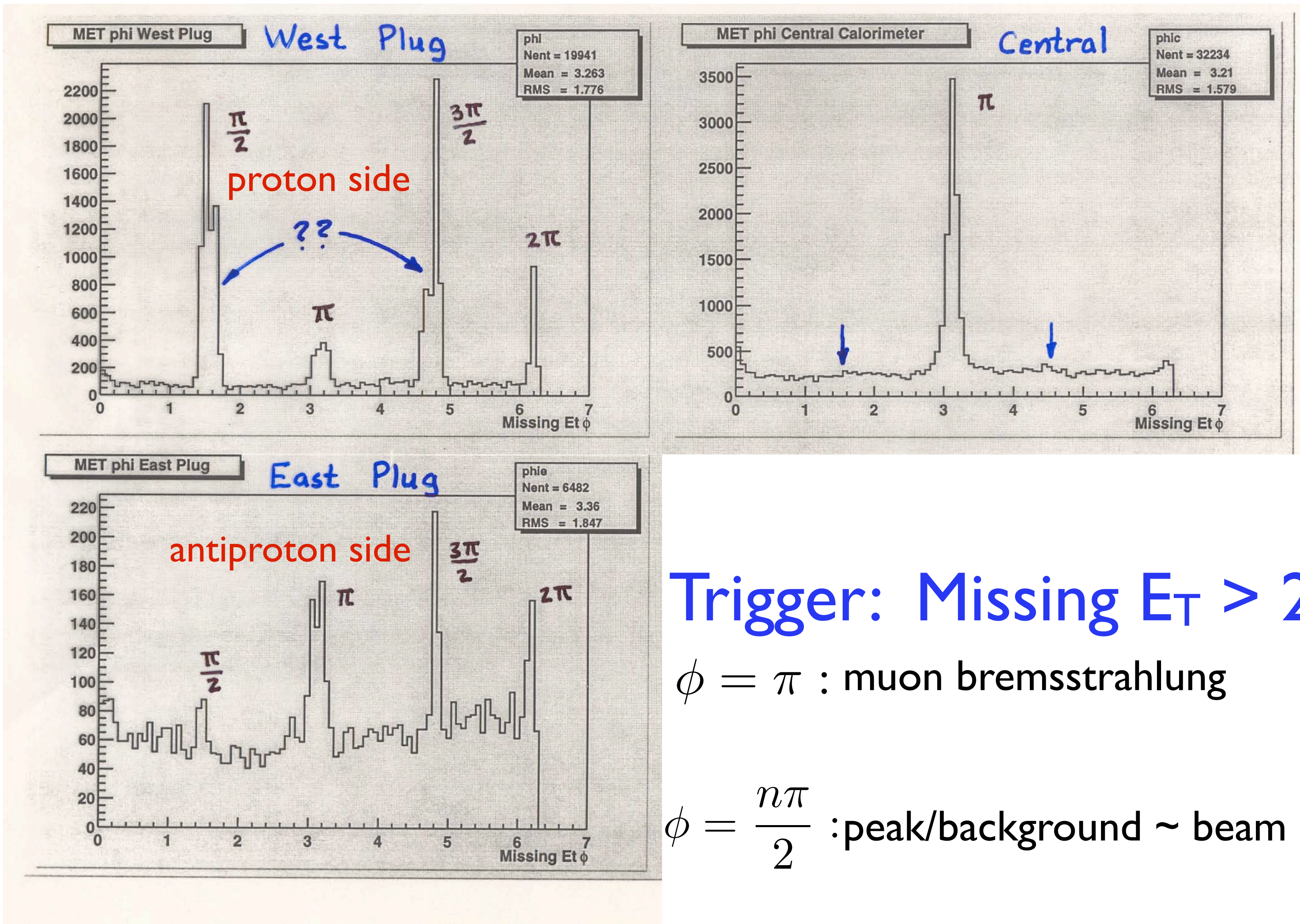
$$Ratio = R_{shielding}/R_{no\ shielding}$$



K.Kordas, *et al.*, IEEE-NSS/MIC Portland, OR (2003)

Jet/Missing E_T Backgrounds

W trigger requires energy imbalance in calorimeters.



Trigger: Missing E_T > 25 GeV

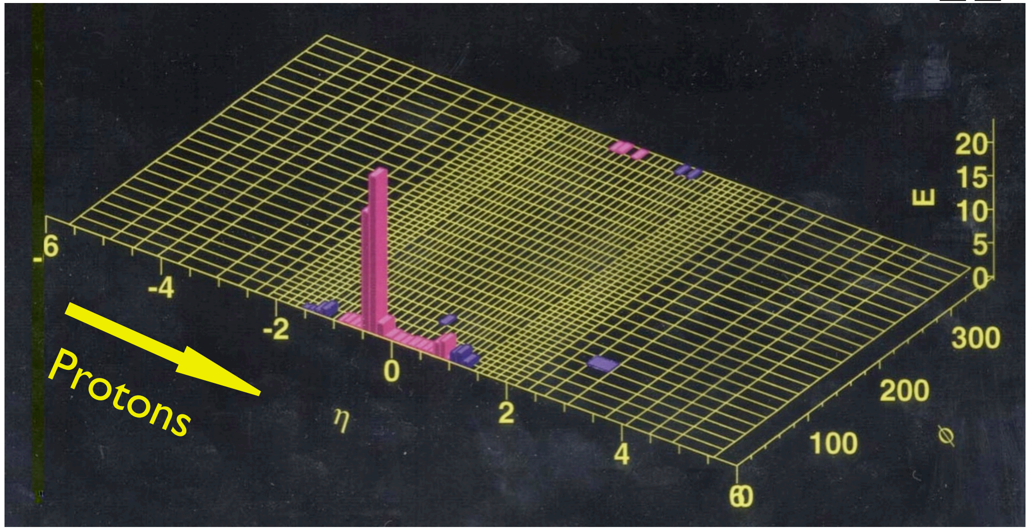
$\phi = \pi$: muon bremsstrahlung

$\phi = \frac{n\pi}{2}$:peak/background ~ beam current

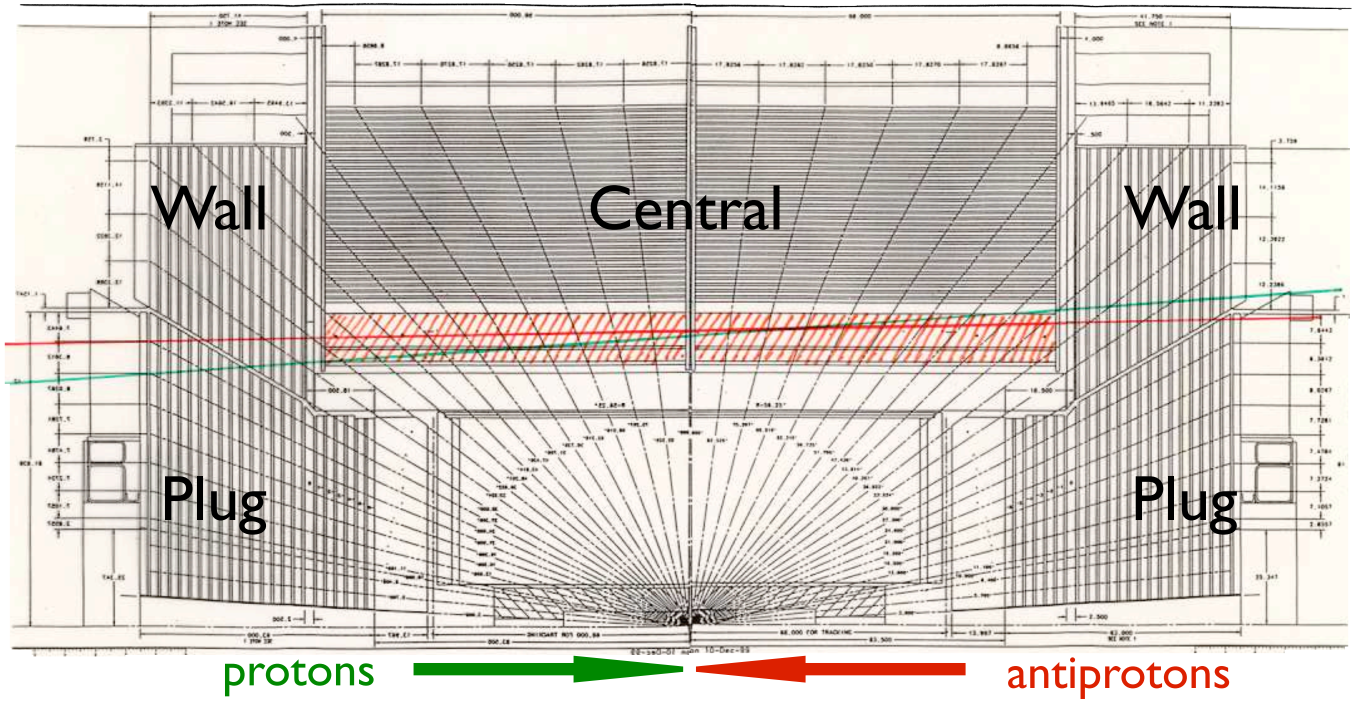
"Jet/MET" Background Events

Events show "track" in calorimeter

- High energy muon
- Beam "halo" hitting Roman pot detectors



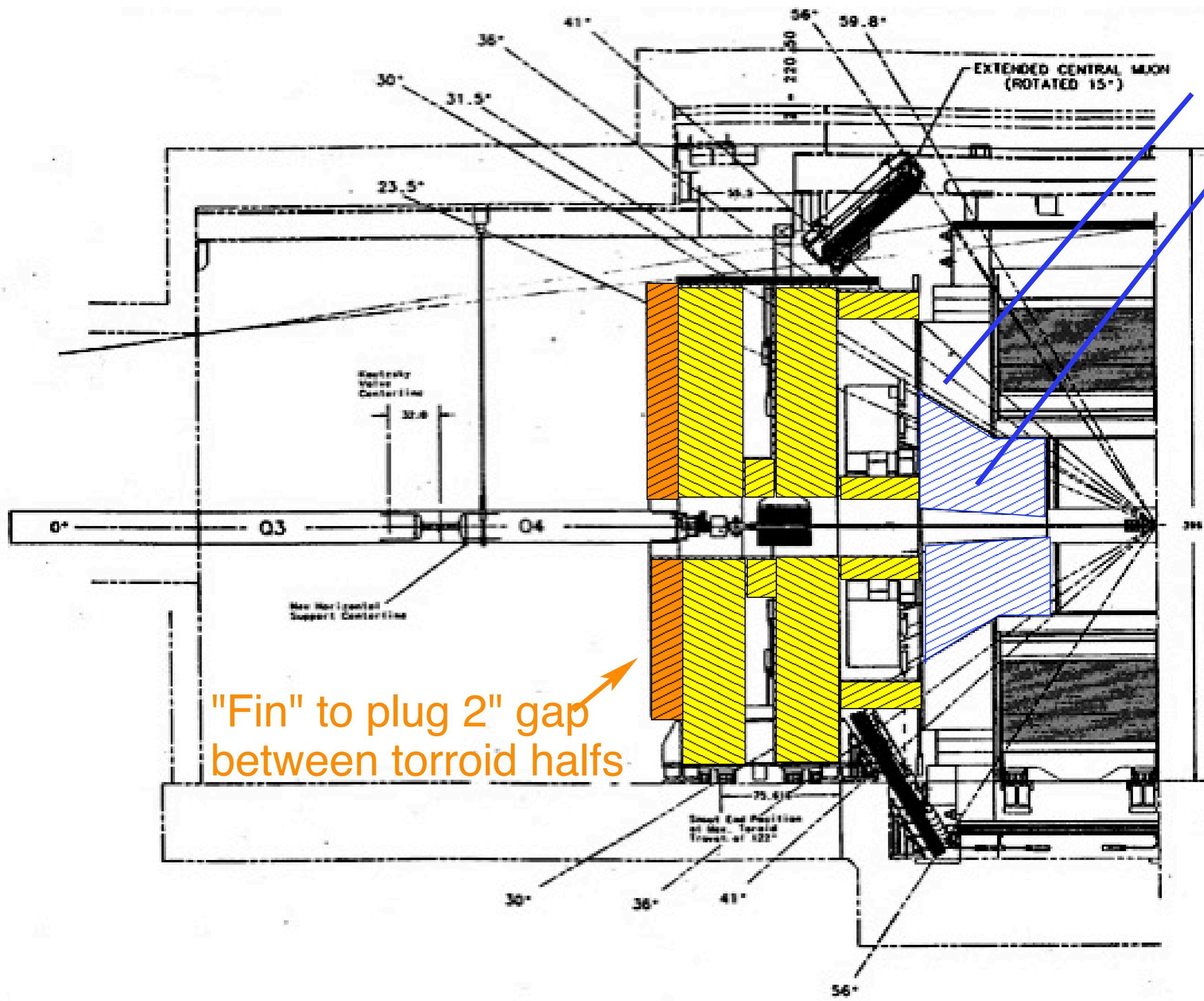
Calorimeter Schematic

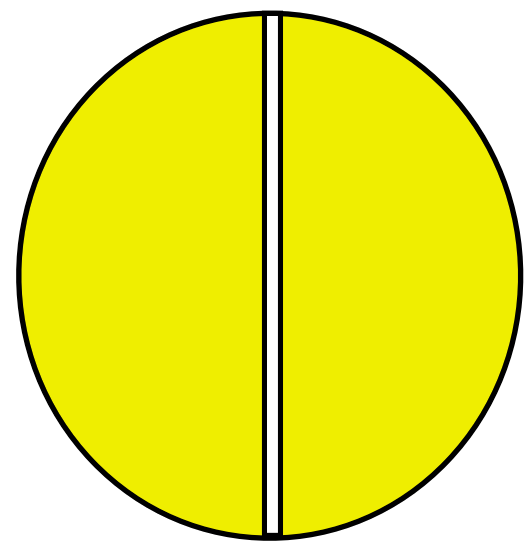


Particle "tracks"

Plug Calorimeter Backgrounds

Gaps in shielding aligned with backgrounds





Analysis Cuts Remove Backgrounds

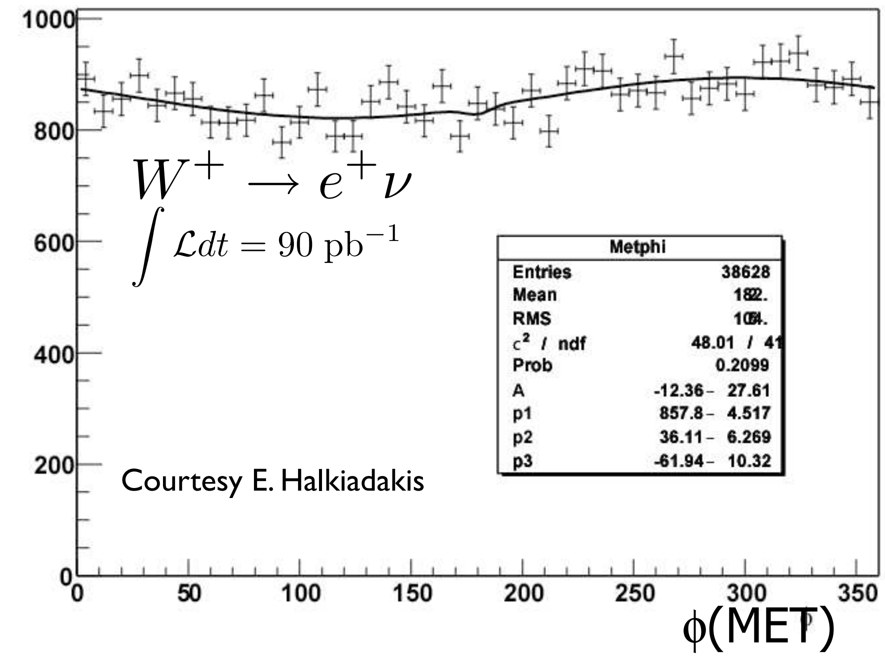
W Decay: $W^+ \rightarrow e^+\nu$

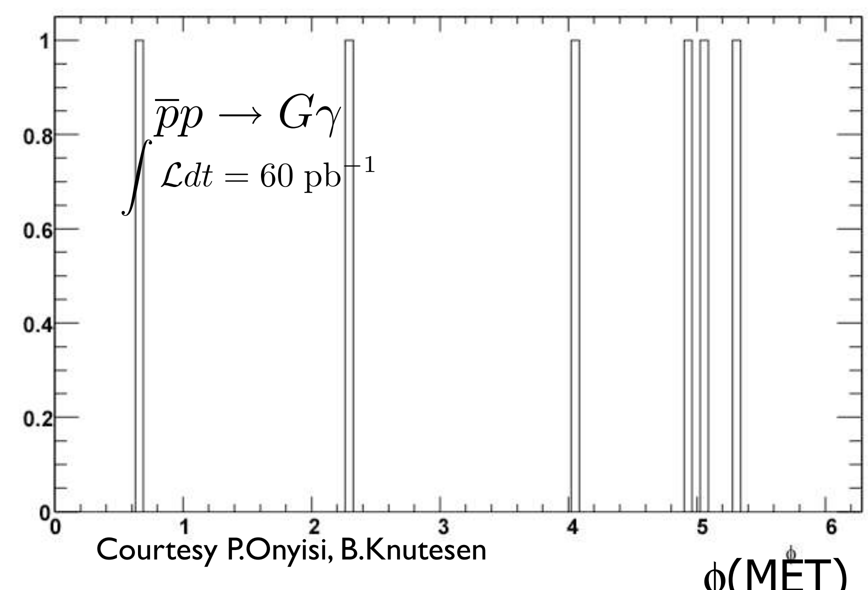
- Require energy matched to track
- signal:halo >358:1 (95%CL)

Graviton search: $\bar{p}p \rightarrow G\gamma$

- Require good EM shower shape
- Require no contiguous energy in φ slice.
- Limited by Standard Model processes: $Z^0 \rightarrow \nu\bar{\nu}\gamma$
- Z background:halo >16:1 (68%CL)

Advances in selection criteria give halo suppression >1000





Halo (Beam Loss) Reduction

Vacuum problems identified in 2m long straight section of Tevatron (F sector ~ 1km from detector!)

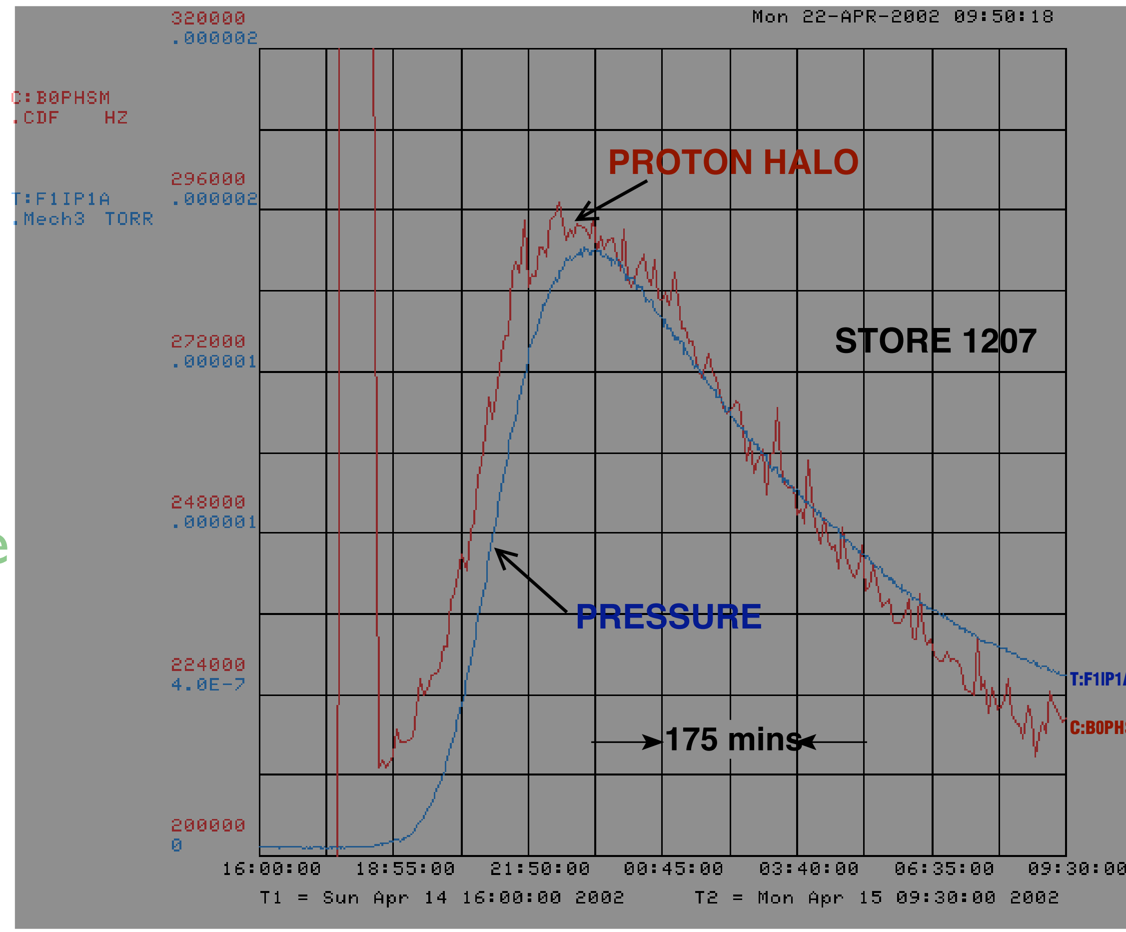
Improved vacuum (TeV wide)

Commissioning of collimators to reduce halo

- Halo/proton reduced by factor of 10.
- Physics backgrounds reduced by ~40% in some triggers

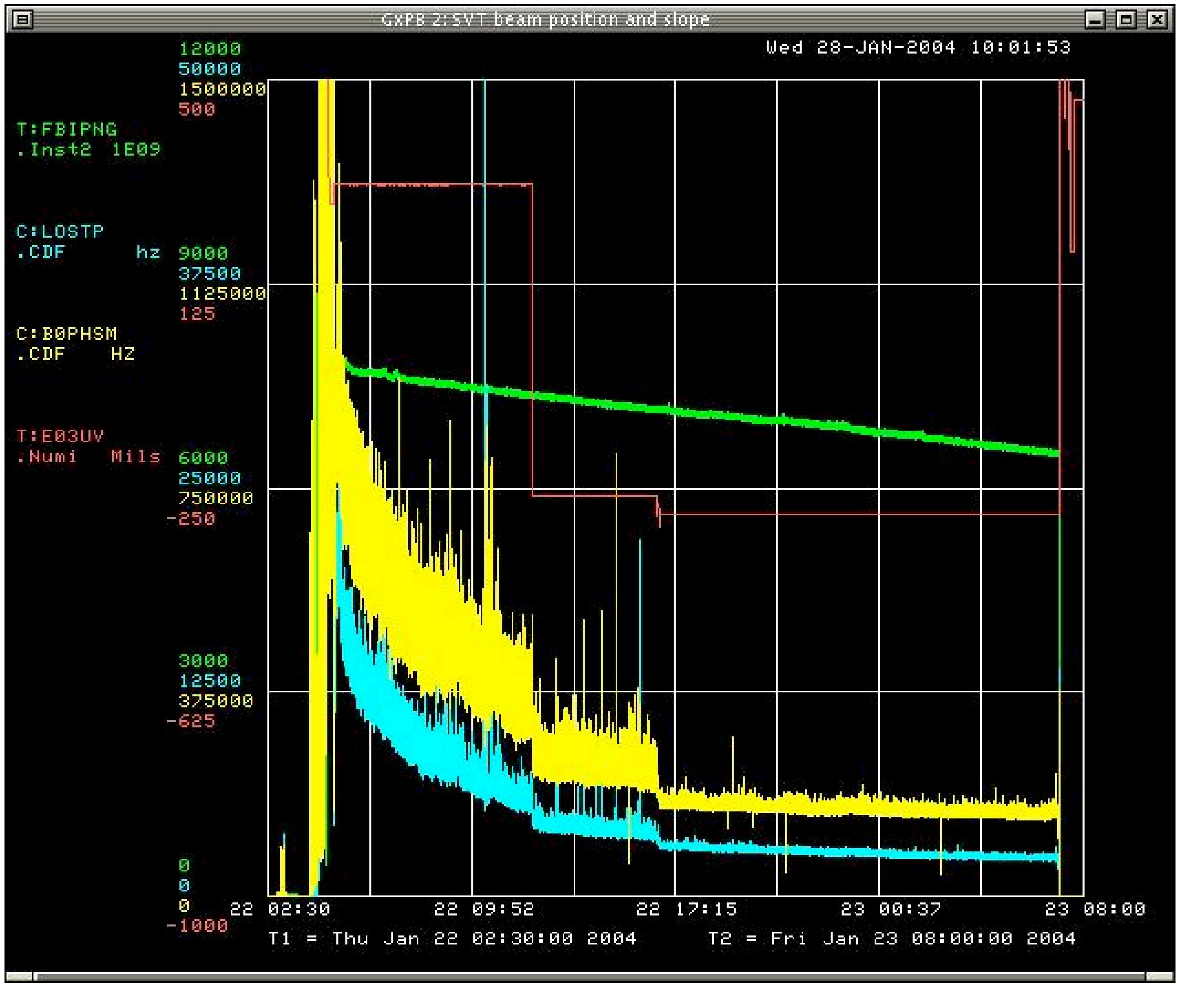
Requires good beam quality monitoring

Collaborative effort between experiment and accelerator



R. Moore, V. Shiltsev, N.Mokhov, A. Drozhdin

Collimators in Action



E0 collimator

proton beam current

proton halo

proton losses

Improvements

2004 shutdown

- adjust low beta quads/magnet unroll
- dipole coil lift (skew quad component)
- Added separators (wider separation of beams)
- Moved Dzero separators

2005 shutdown

- adjust low beta quads/magnet unroll

2006 shutdown

- adjust low beta quads/magnet unroll

2007 shutdown

- adjust low beta quads/magnet unroll

Typical Store (2004)

Beam Parameters:

Protons:	5000 - 9000	10^9 particles
Antiprotons:	500-1500	10^9 particles
Luminosity:	30 - 70	$10^{30}\text{cm}^{-2}\text{s}^{-1}$

Losses and Halo:

Quantity	Rate (kHz)	Limit (kHz)	comment
P Losses	2 - 15	25	chambers trip on over current
Pbar Losses	0.1 - 2.0	25	chambers trip on over current
P Halo	200 - 1000	-	
Pbar Halo	2 - 50	-	
Abort Gap Losses	2 - 12	15	avoid dirty abort (silicon damage)
L1 Trigger	0.1 - 0.5		two track trigger (~1 mbarn)

Note: All number are taken after scraping and HEP is declared.

Typical Store (2005)

Beam Parameters:

Protons:	5000 - 10000	10^9 particles
Antiprotons:	500-1800	10^9 particles
Luminosity:	50 - 170	$10^{30}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

Color Codes

better than 2004
worse than 2004
no change

Losses and Halo:

Quantity	Rate (kHz)	Limit (kHz)	comment
P Losses	0.1 - 0.5	25	chambers trip on over current
Pbar Losses	0.1 - 3.0	25	chambers trip on over current
P Halo	15 - 18	-	
Pbar Halo	20 - 100	-	
Abort Gap Losses	0.1 - 15	25	avoid dirty abort (silicon damage)
L1 Trigger	0.1-0.5		two track trigger (~1 mbarn)

Note: All number are taken after scraping and HEP is declared.

Typical Store (2007-8)

Beam Parameters:

Protons:	5000 - 10000	10^9 particles
Antiprotons:	1000-3000	10^9 particles
Luminosity:	50 - 300	$10^{30}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

Color Codes

better than 2005
worse than 2005
no change

* High losses for first 2 hrs of store (decreasing rapidly) nearly steady state at lower value thereafter.

Losses and Halo:

Quantity	Rate (kHz)	Limit (kHz)	comment
P Losses	0.05 - 15*	25	chambers trip on over current
Pbar Losses	0.02 - 3.0*	25	chambers trip on over current
P Halo	3 - 100*	-	
Pbar Halo	40 - 100*	-	
Abort Gap Losses	0.5 - 1.5*	25	avoid dirty abort (silicon damage)
L1 Trigger	0.1-0.5		two track trigger (~1 mbarn)

Note: All number are taken after scraping and HEP is declared.

Observations/Summary

Accelerator Backgrounds (Losses)

- Beam is not always where you think it is (abort gaps)
- Beam losses may cause operational problems/physics backgrounds
- Origins of backgrounds may be far from detectors
  + Understanding losses <==> understand detector and accelerator
  + dialog between experiment and accelerator crucial
- Real time beam monitoring important
- Measurement of backgrounds early helps identify potential problem areas

Final Note

"If you know the enemy and know yourself, you need not fear the result of a hundred battles"
-- Sun Tzu, The art of War (6th century B.C.)

Summary

Control of backgrounds important at CDF

- Detector operations
- Physics backgrounds

Backgrounds from

- Focusing triplet is a line source
- Local aperture restrictions
- "Incomplete collimation"

} Accelerator control of beam

Solutions

- Shielding + Experiment (Accelerator)
- Collimation + Accelerator (Experiment)
- Alignment + Accelerator (Experiment)
- Monitoring of beam conditions + Accelerator/Experiment
- Analysis selection (physics) + Experiment

Exchange between experiment and accelerator

References (Incomplete List)

General:

- http://ncdf67.fnal.gov/~tesarek

Single Event Effects:

- R.J. Tesarek, *et al.*, Proceedings IEEE-NSS/MIC Conference, El Conquistador Resort, Fajardo, Puerto Rico, October 22-30 (2005).

Beam Quality and Instrumentation:

- http://www-cdfonline.fnal.gov/acnet/ACNET_beamquality
- M.K. Karagoz-Unel, R.J. Tesarek, *Nucl. Instr. and Meth.*, **A506** (2003) 7-19.
- A.Bhatti, *et al., CDF internal note*, **CDF 5247**.
- D. Acosta, *et al., Nucl. Instr. and Meth.*, **A494** (2002) 57-62.
- A. Drozhdin, *et al., Proceedings: Particle Accelerator Conference(PAC03),* Portland, OR, 12-16 May 2003.
- L.Y. Nicolas, N.V. Mokhov, *Fermilab Technical Memo:* **FERMILAB-TM-2214** June (2003).

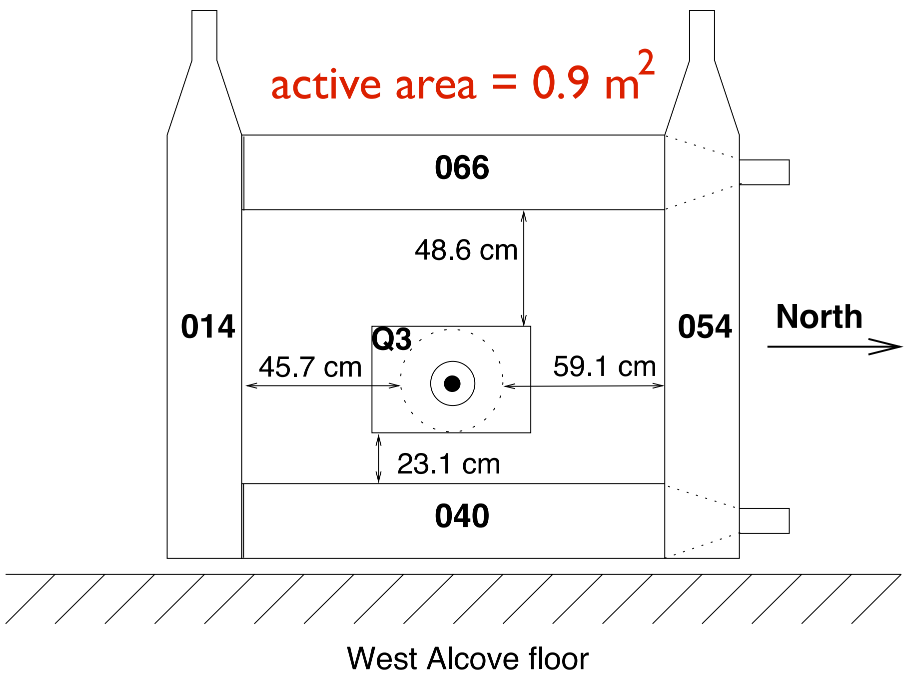
Radiation:

- http://ncdf67.fnal.gov/~tesarek/radiation
- S. d'Auria, *et al., Nucl. Instr. and Meth.*, **A513** (2003) 89-93.
- K. Kordas, *et al., Proceedings: IEEE-NSS/MIC Conference,* Portland, OR, November 19-25 (2003).
- R.J. Tesarek, *et al., Proceedings: IEEE-NSS/MIC Conference,* Portland, OR, November 19-25 (2003).

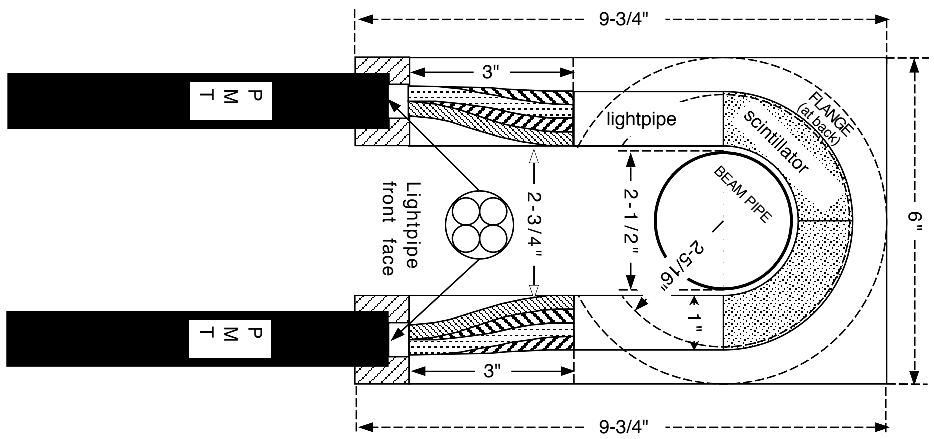
Backup/Supplemental Slides

Beam Halo Loss Detectors

Halo Counters



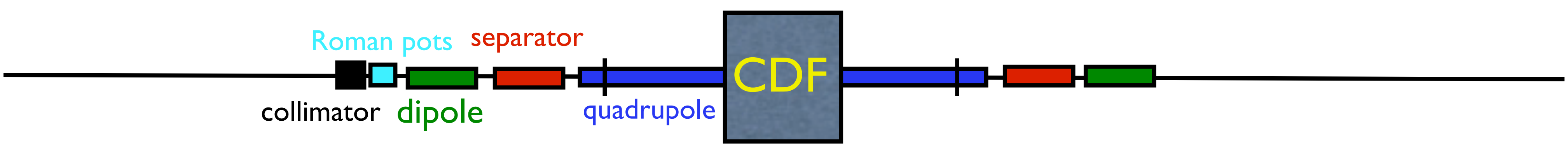
Beam Shower Counters



ACNET variables:

B0PHSM: beam halo
B0PBSM: abort gap losses
B0PAGC: 2/4 coincidence abort gap losses
B0PLOS: proton losses (digital)
LOSTP: proton losses (analog)

Beam Halo Counters



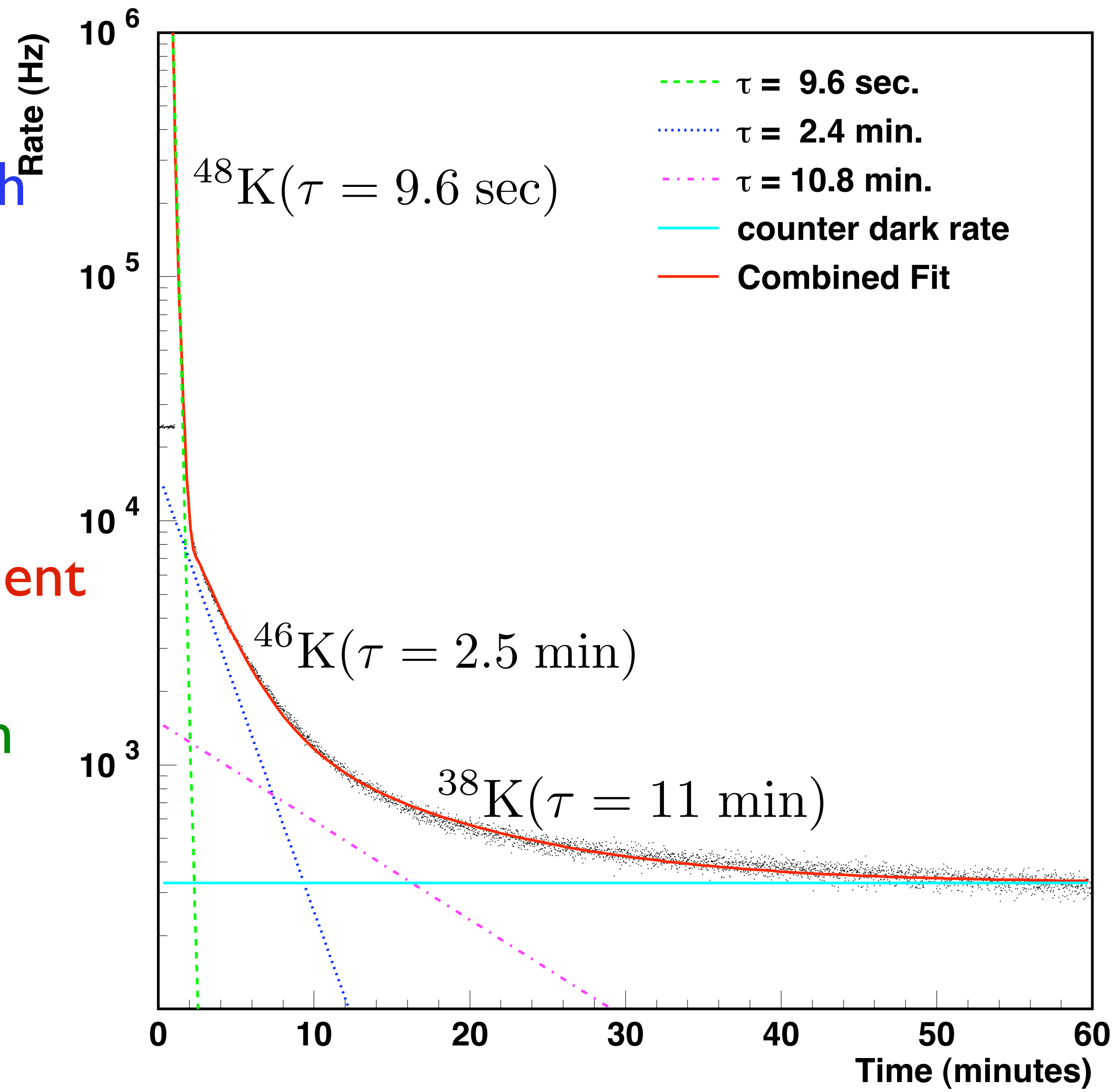
Activation Background in Counters

Activated quadrupole steel

- Periods of sustained high losses
- Large beam "accident"
- β radiation mostly
- Lose timing info
- Contaminate measurement

Majority 2/4 coincidence

- Reduces contamination
- Reduces overall rate
- Insensitive to single particles



Neutron Spectrum Measurement

Polyethylene "Bonner" spheres

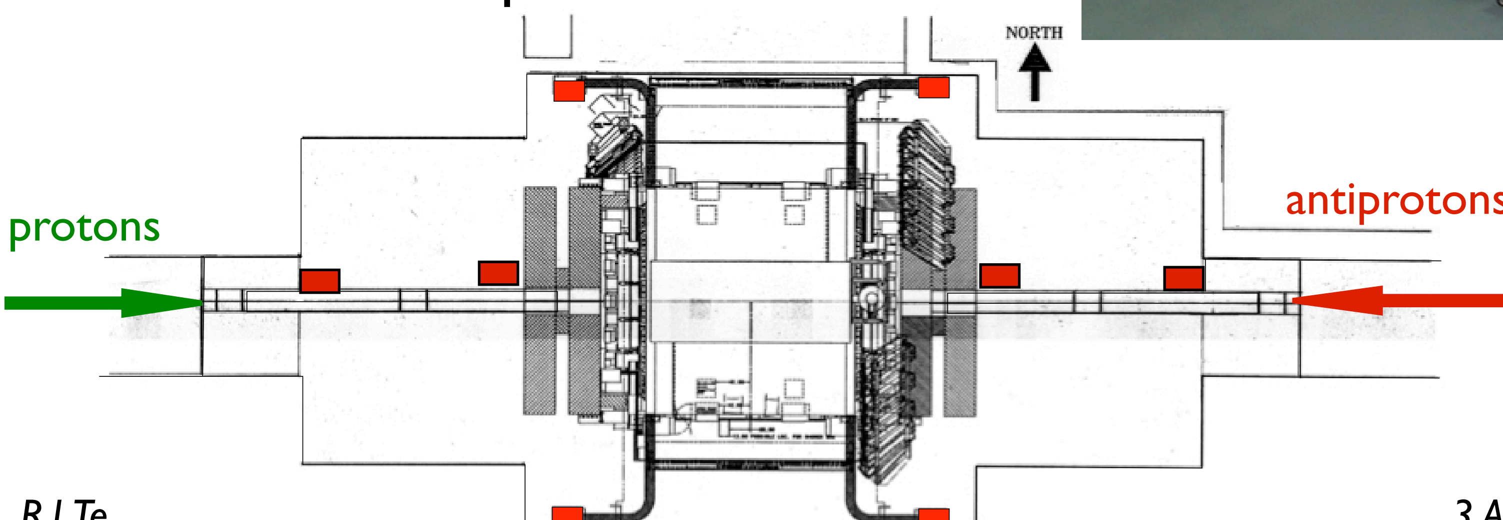
Evaluate Neutron Energy Spectrum

- Bonner spheres + TLDs
- ~1 week exposures
- Shielding in place

Measuring neutrons is hard

Work in progress...

Bonner sphere locations



Neutron Data

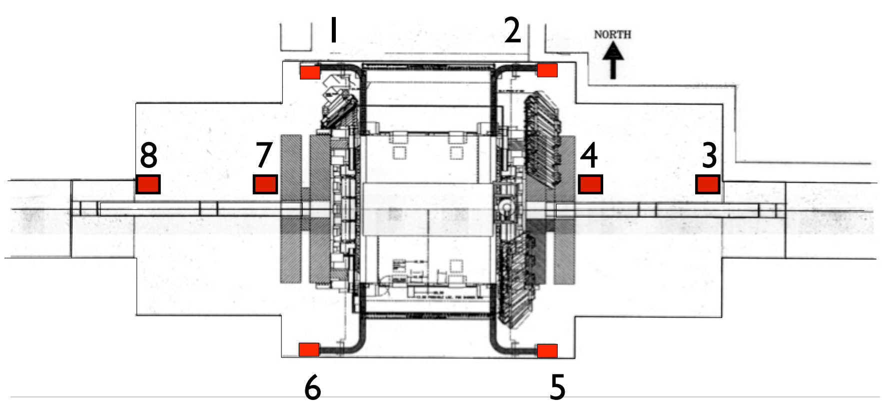
Compare data with ^{252}Cf

- spontaneous fission
- ~20 n/decay
- $\langle E_n \rangle$ ~2 MeV

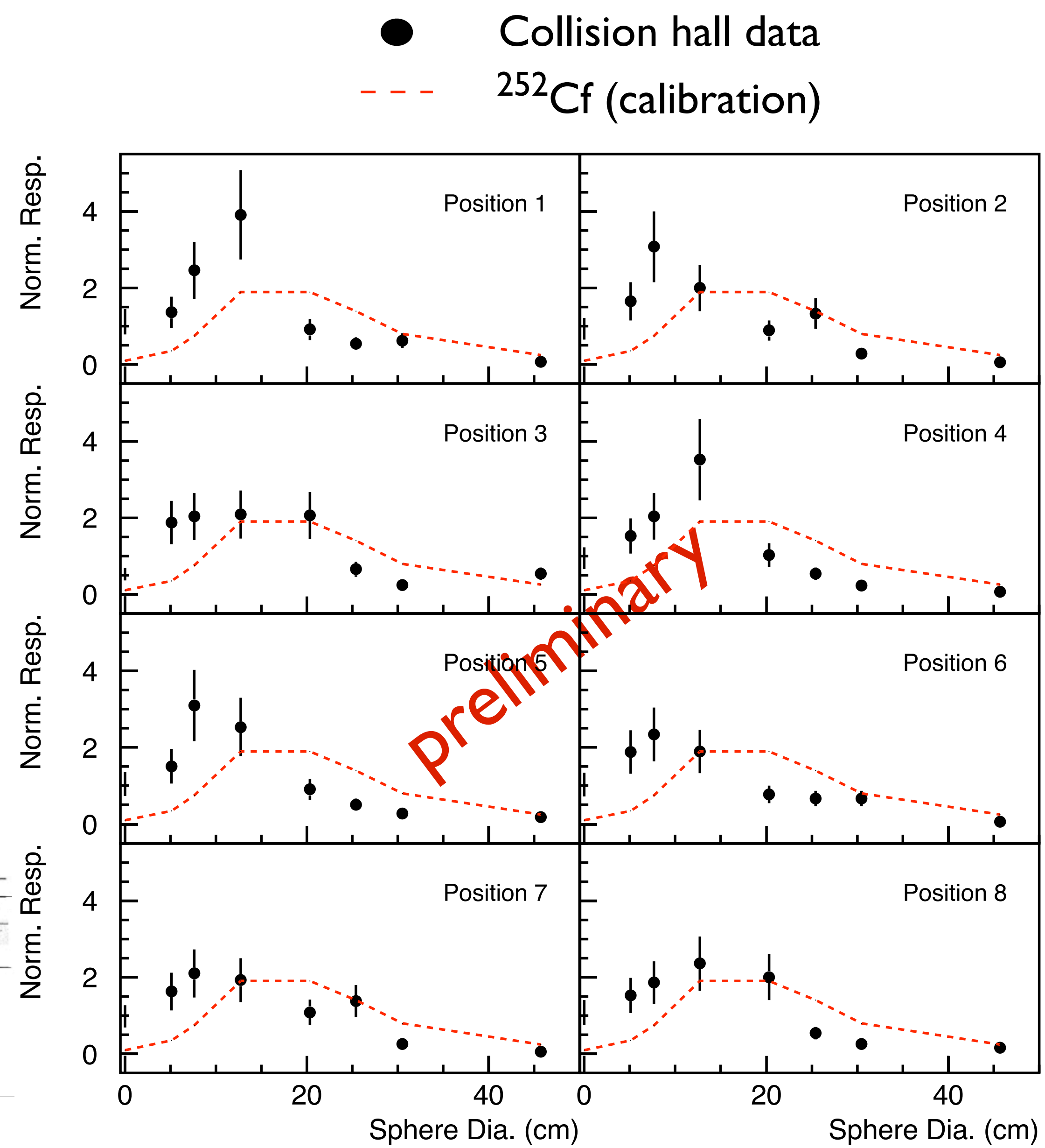
Data show average E_n < 2 MeV

To do:

- understand E_n distribution
- neutron fluence



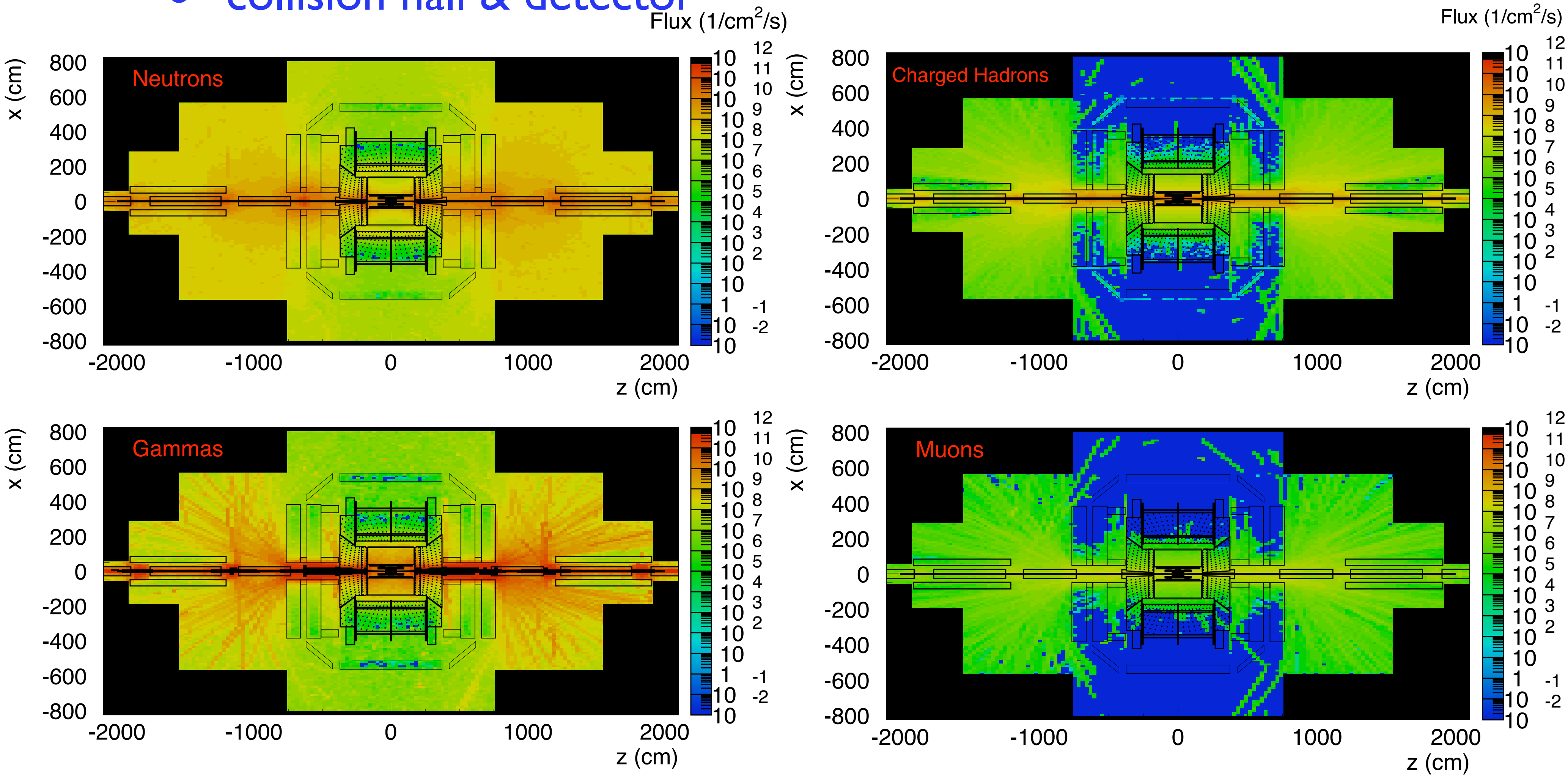
W. Schmitt, *et al.*



Simulated Radiation Environment

Detailed MARS simulation of:

- accelerator & beam transport
- collision hall & detector

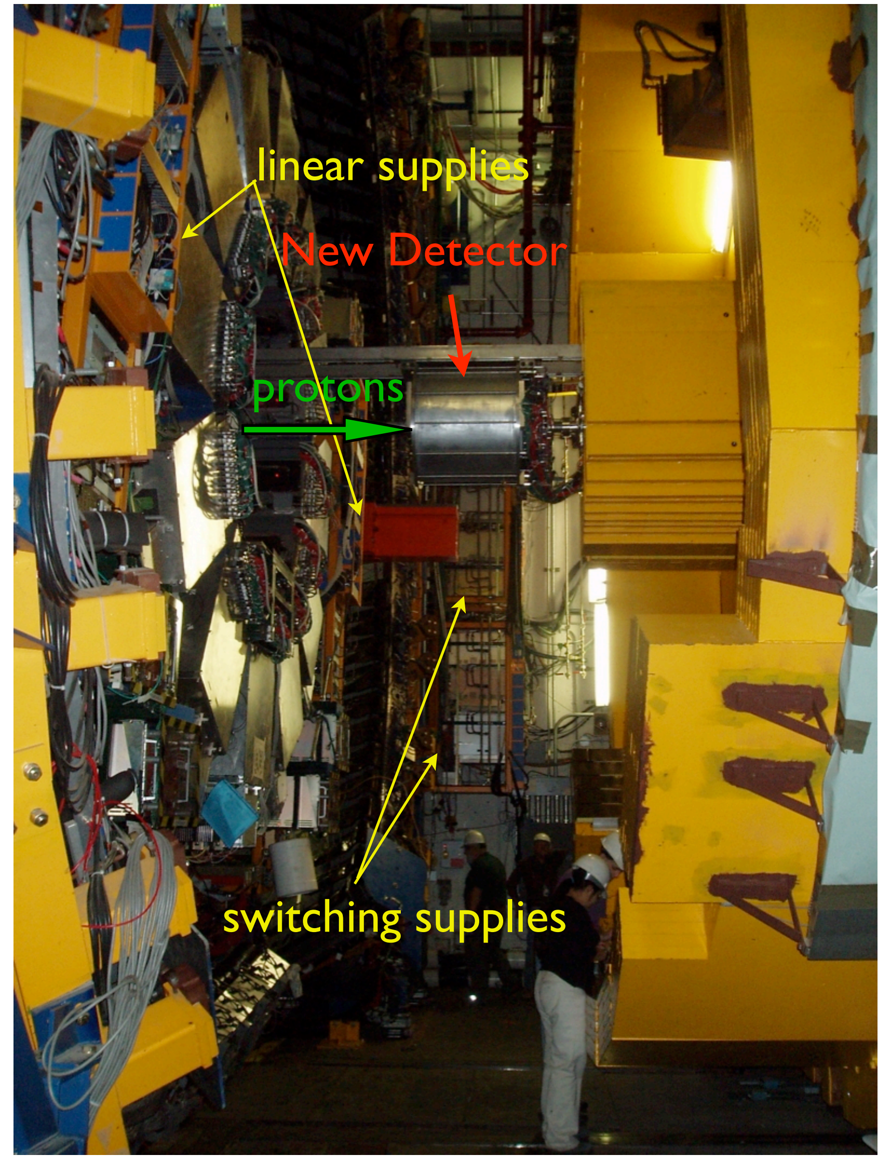


St Catherine's Day Massacre

12 switching power supplies failed in an 8 hour period.

- only during beam
- only switching supplies
- failures on detector east side
- shielding moved out
- new detector installed
- beam pipe misaligned

Conclusion: Albedo radiation from new detector

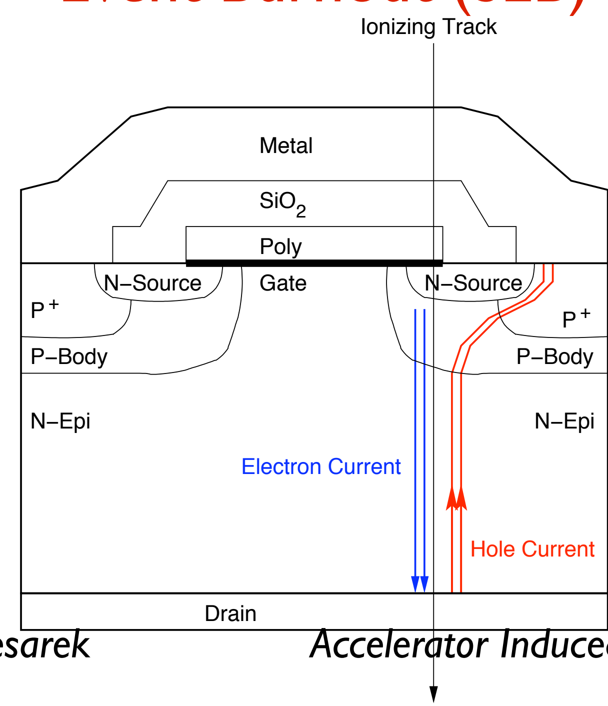


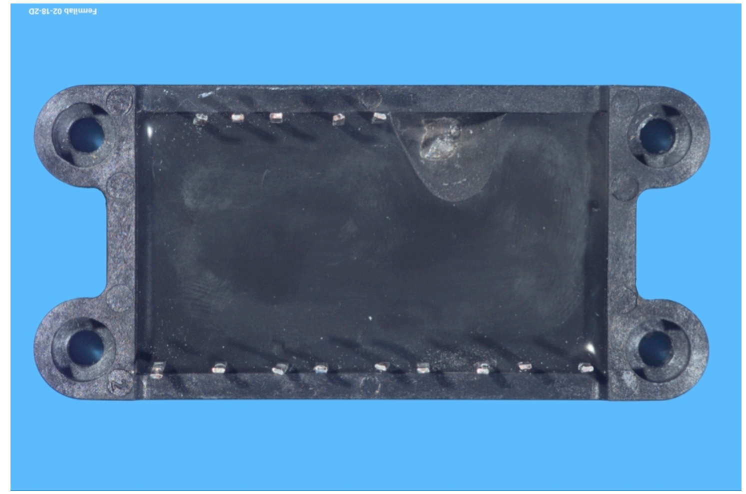
L.V. Power Supply Failures

Power Factor Corrector Circuit

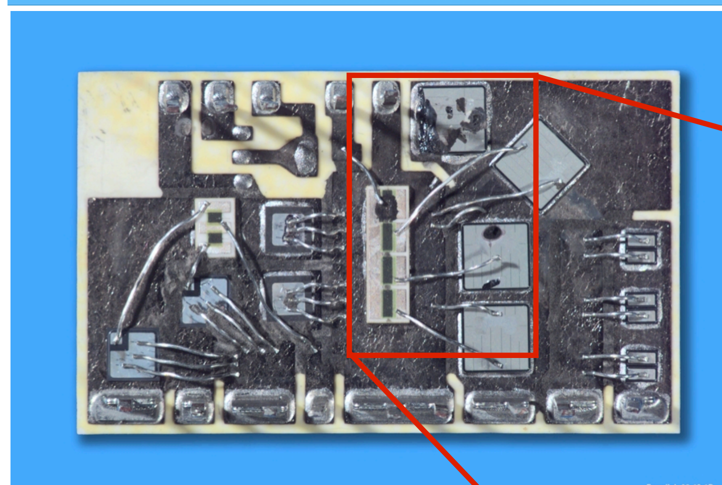
Most failures were associated with high beam losses or misaligned beam pipe

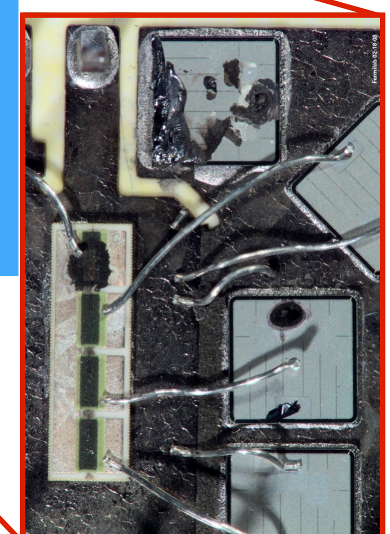
> Power MOSFET Single Event Burnout (SEB)





epoxy covering fractured





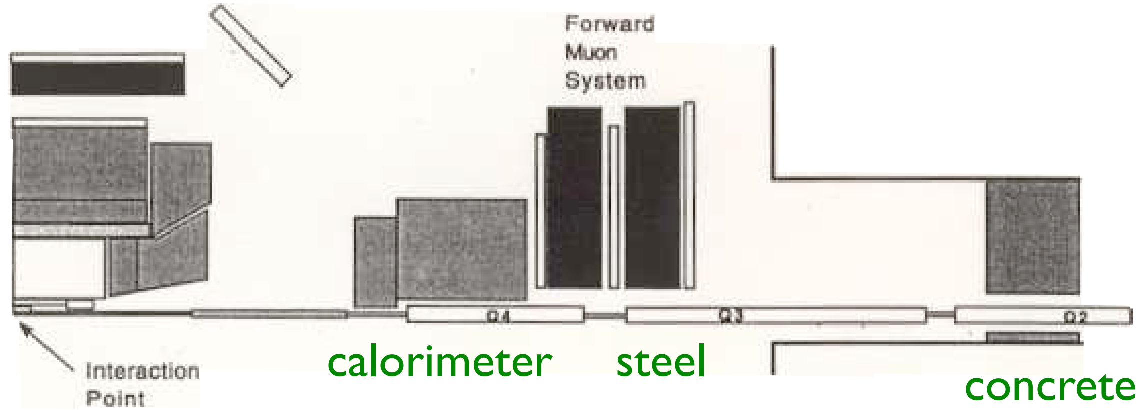
silicon in MOSFET sublimated during discharge through single component

Run I Shielding

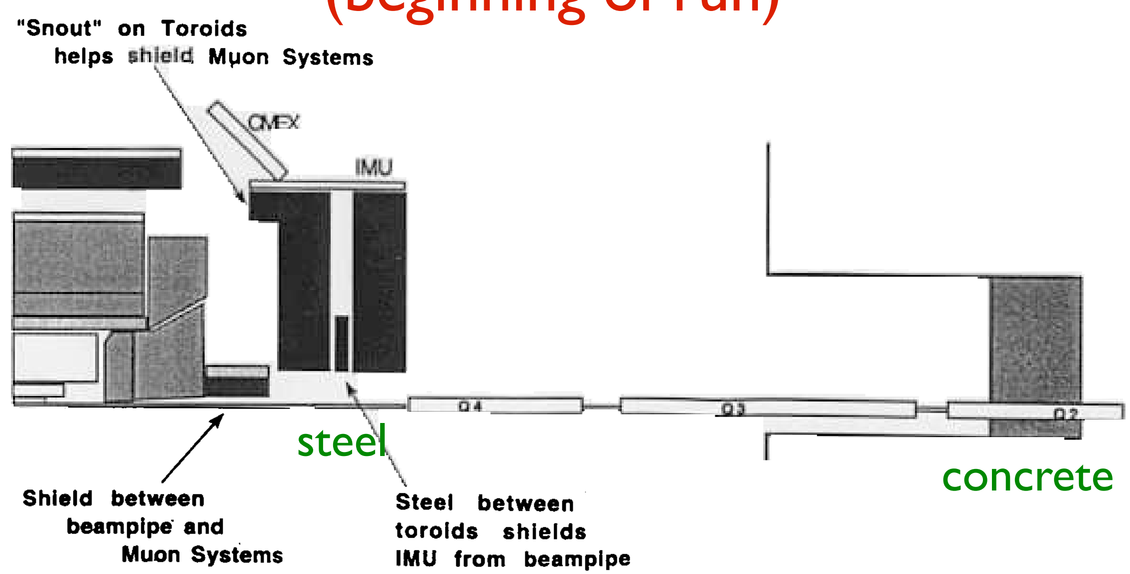
Detector configuration different in Run II

- Run I detector "self shielded"
- Additional shielding abandoned (forward muon system de-scoped).
- Shielding installed surrounding beam line.

Run I Shielding



Run II Shielding (beginning of run)



Silicon Detector Dose (Damage)

Measure I_{bias}

- correct Temp. to 20C
- $\alpha_{damage}=3.0\times10^{17}$ A/cm

Early comparison with TLD Data

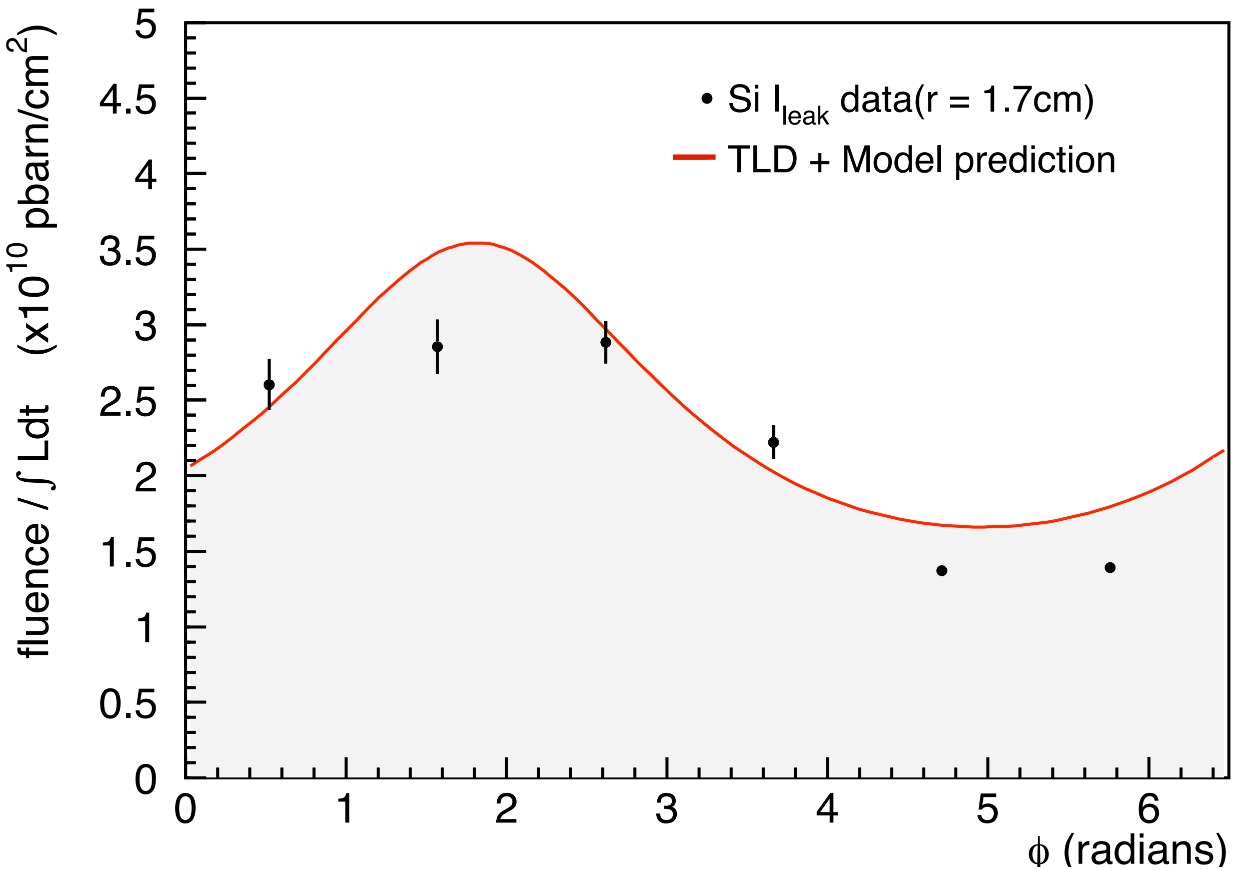
- Assume $r^{-\alpha}$ scaling
- $1 Gy=3.8\times10^{9}$ MIPS/cm^2

Temp profile of SVX sensors poorly understood.

Update with full tracker in 2005.

P. Dong

L00 damage: 15 pbarn^{-1}



Note: Beam offset 5mm from detector axis

Simulated Ionizing Radiation

MARS simulation of CDF

- Collisions simulated by DPMJET
- Simulation scaled up 2x for plot (check shape)

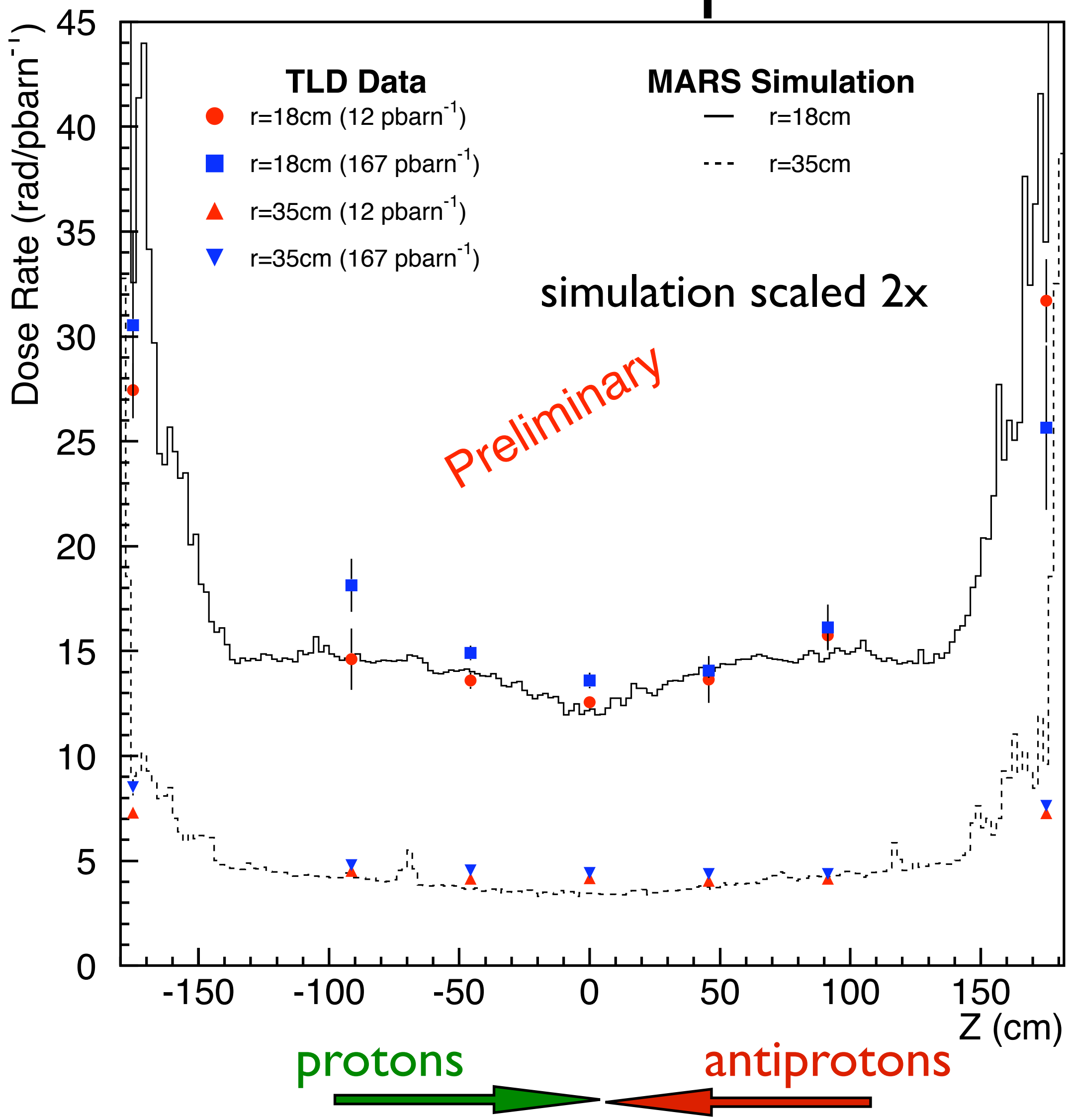
Missing Material?

- electronics
- cables
- cooling

\+ Qualitative understanding of collision dose (dominant)

\- Losses not understood!

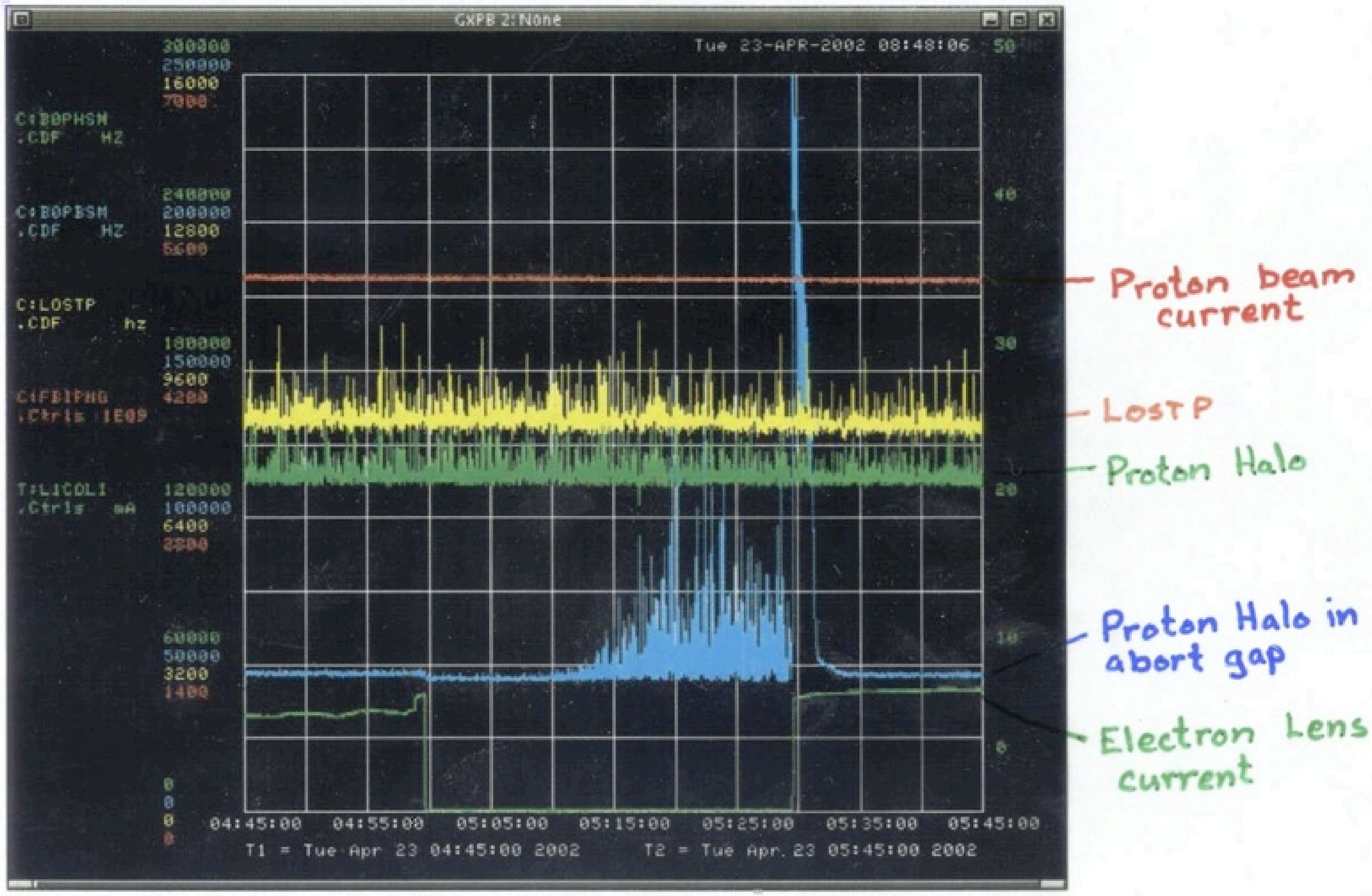
Collision Component



Electron Lens Abort Gap Cleaning

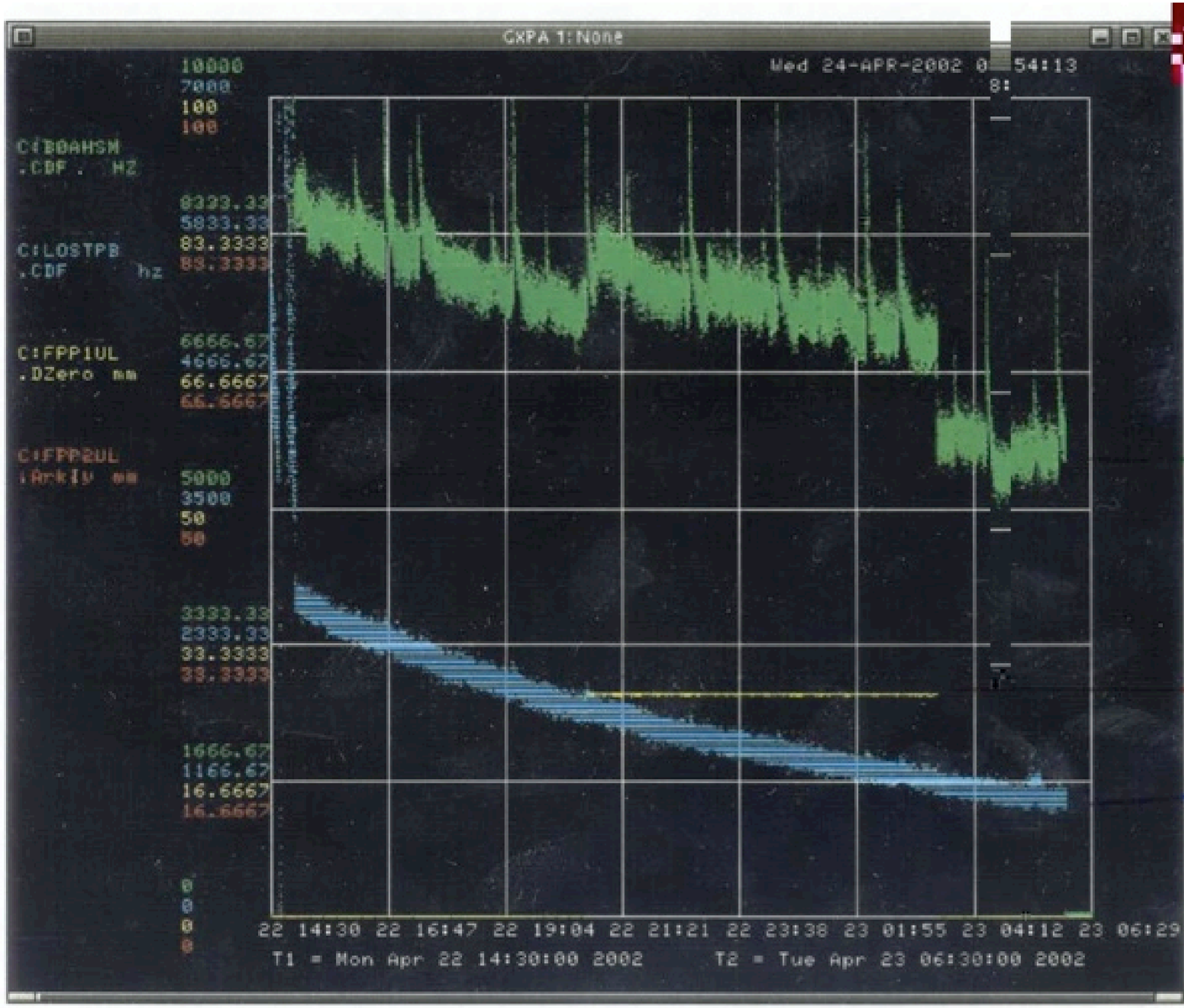
Store 1229

Proton Info...

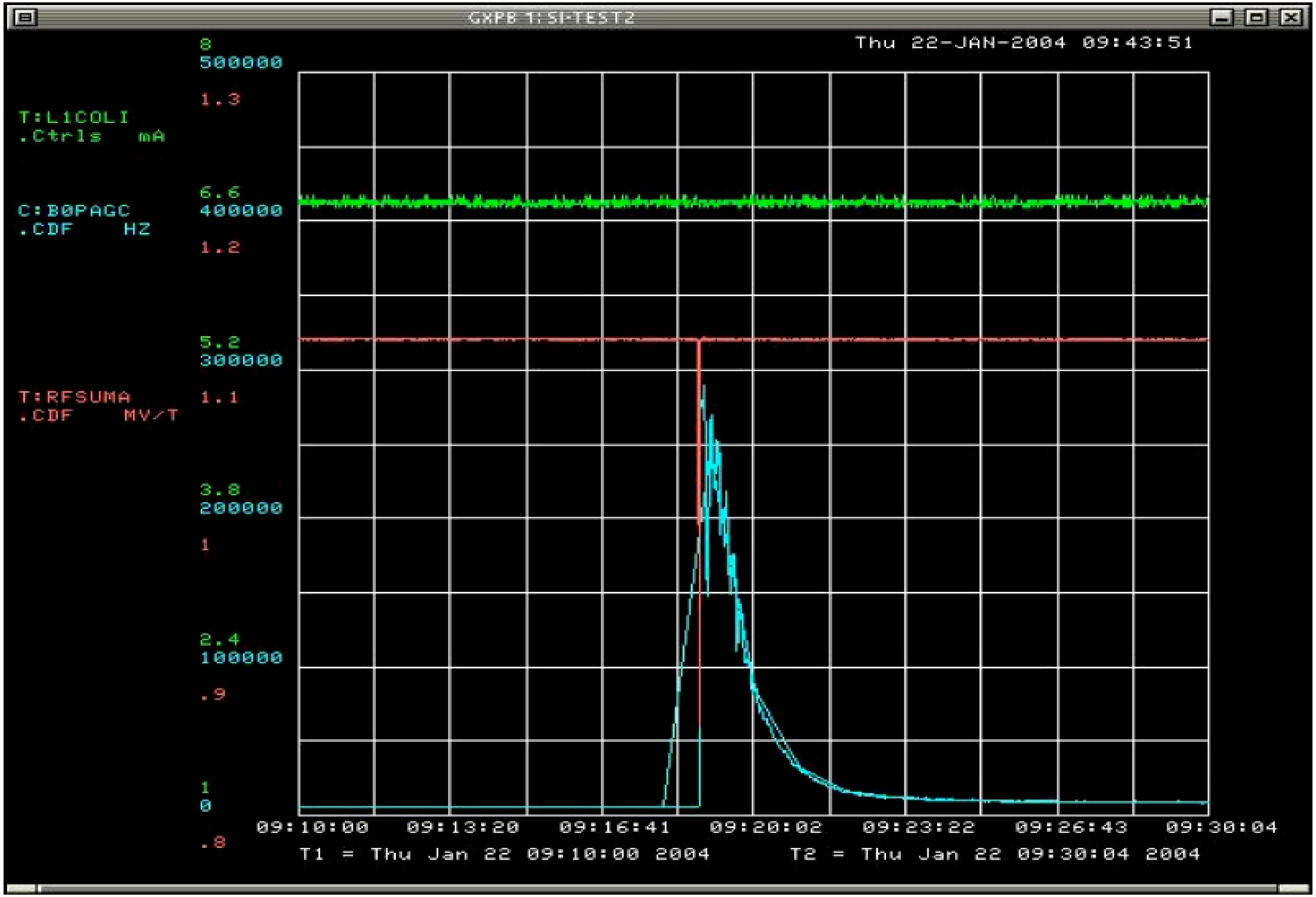


Close
Duplicate

“Poor Collimation” Example



RF Glitch



Sum RF voltage

Abort Gap Losses